RISK FACTORS AFFECTING SEVERE THORACIC INJURIES OF OCCUPANTS BASED ON AGE GROUPS AND FRONTAL OBLIQUE COLLISIONS

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ABSTRACT

Frontal collision is the most common type of motor vehicle collision occurring in real-world collisions. This study aims to investigate the risk of thoracic injury depending on age and oblique direction of collision in a frontal collision.

This was a retrospective, observational study. The study used the Korean In-Depth Accident Study (KIDAS) database. We selected 1,369 adult occupant patients in frontal collisions and seated only in the first row. The severely injured occupants were defined as those who had AIS3+ injury in thoracic regions. The age of occupants was classified into three groups: <54 years, 55-64 years, and >65 years. The frontal oblique collision was classified by the PDoF. Considering the PDoF, occupants were classified into three groups: Far-frontal oblique, Near-frontal oblique, and longitudinal.

The risk of thoracic injury was significant in age, seating position, and delta-V parameters. 55-64 years occupants OR was 1.819 compared to <54 years. In addition, >65 years occupants OR were 1.950, a higher value. The frontal passenger seat had a lower risk of thoracic injury than the driver seat (OR = 0.465). An increase of 1kph delta-V made a 1.018 OR rise. The oblique direction was only significant in the occupants with fastened seatbelts. The OR of the near-frontal oblique direction was 2.964 compared to the far-frontal oblique direction. The OR of the longitudinal direction was 2.229. Occupants with unfastened seatbelts had no risk difference in the oblique parameter.

The study result showed that elderly occupants had a higher risk of severe thoracic injury. Furthermore, the oblique collisions affected to the risk of severe injury only seatbelt fastened occupants. This study showed the detailed risk of the thoracic region using the real-world collision database. The research could be used to enhance occupant safety and advance the crashworthiness of vehicle structures.

INTRODUCTION

Motor vehicle collisions are one of the global leading causes of death. In 2016, global mortality from motor vehicle collisions was 18.2 per 100,000 people, and mortality is declining every year [1,2]. The injury regions to contribute to the cause of death in collisions are various. Among the regions, the thorax is highly exposed to mortality and severe injury rates in motor vehicle collisions after the head region [3]. The thorax is a huge area in the human body that contains vital organs for life. Therefore, continuous research on the reduction of thoracic injuries is needed.

Motor vehicle collisions are classified differently according to the type of collision scenario. Classification using the collision direction of the vehicle is intuitively easy to understand. This is one of the frequently used classification methods [4]. Among the various collision direction, frontal collision is a common type of collision occurring in a real-world motor vehicle collision. The injury severity of the thoracic region is affected by frontal oblique collisions that collide with objects at an angle [5]. However, there are insufficient studies to analyze the factors of thoracic injury through statistical methods for frontal oblique collisions based on real-world collisions. Therefore, there is a need for a study analyzing the risk of thoracic injury in a frontal oblique collision using parameters from a real-world collision database.

Even in the same type of collisions, the injury severity of occupants can be different [6]. The reliability of the analysis of injury characteristics resulting from collisions can be ensured by considering the human factors of the occupants [7]. In particular, the age parameter must be considered in the analysis of occupant injuries. Globally, life expectancy is rising. This phenomenon increases the number of elderly occupants on the roadways. Elderly occupants are more vulnerable to injury. Particularly, aging is known to strongly increase the risk of severe thoracic injuries [5,8].

This study aimed to investigate the risk of thoracic injury caused by frontal oblique collision. Through this, we would like to find out which oblique scenario increases the injury risk of occupants and how to overcome oblique collisions in the future.

METHOD

Data sources

This study used data from the Korean In-Depth Accident Study (KIDAS) database. This is a real-world motor vehicle collision database that collected occupants' injury data. The data was collected from the occupant patients who visited the emergency department of a regional trauma center in Korea. The period of data collection was 11 years, from January 2011 to February 2022. It also contains vehicle and environmental information obtained through investigation.

Study design

This is a retrospective, observational study. We selected adults and first-row seated occupant patients. The individuals who had unknown injury severity or body mass index (BMI) were excluded. In addition, the analysis excluded occupants who engaged in non-frontal collisions, non-passenger cars, and pole crashes (See Figure 1).

The occupants were classified into two groups according to thoracic injury severity. The abbreviated injury scale (AIS) was used for the classification. The severe injury group had AIS 3+ injury in the thoracic region. The non-severe groups had AIS scores between 0 to 2.

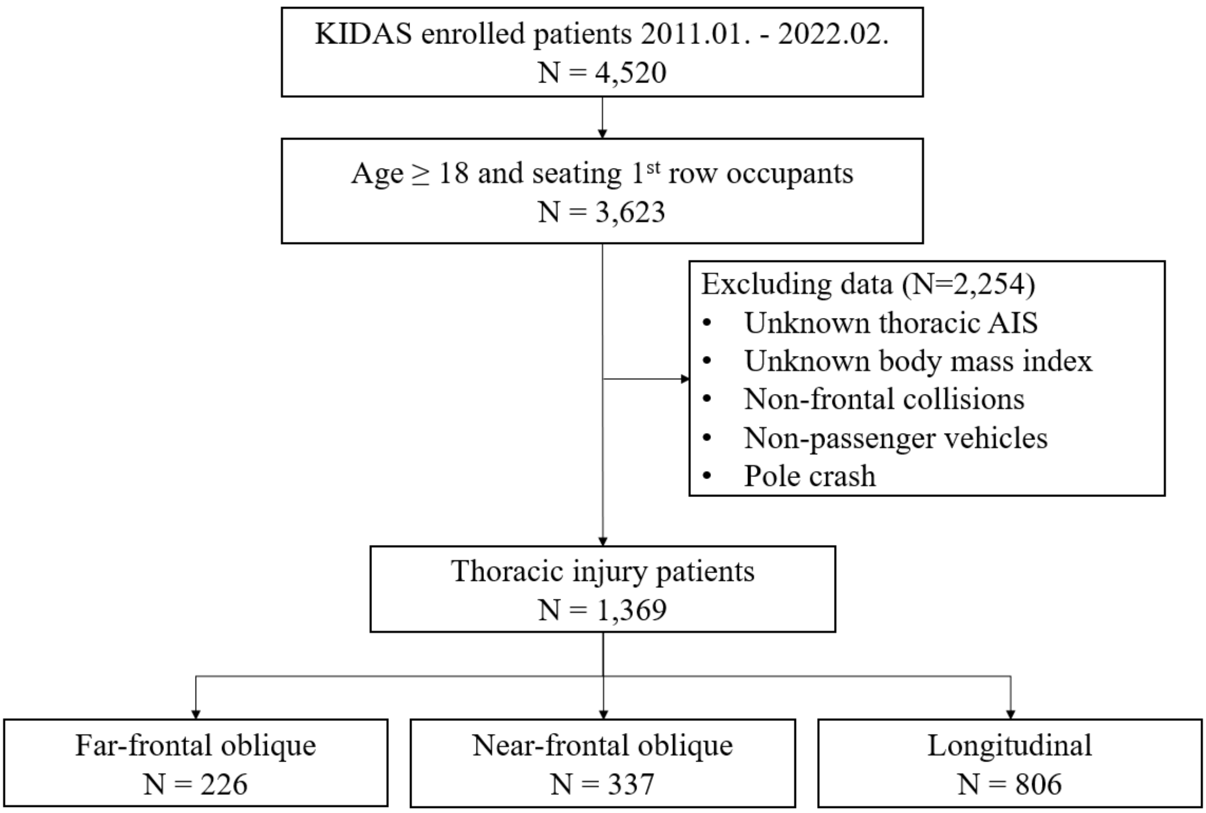

Figure 1. Flowchart of study design

The principal direction of force (PDoF) was used to classify the oblique direction in frontal collisions. All the frontal collisions had major damage to the front part of the vehicle and PDoF between 10 to 2 o’clock. The frontal collisions were classified into three groups considering seating position and PDoF. The driver with 1 and 2 o'clock PDoF and the frontal passenger with 10 and 11 o’clock were classified as far-frontal oblique collisions. The driver with 10 and 11 o’clock PDoF and the passenger with 1 and 2 o’clock PDoF were classified as near-frontal oblique collisions. The longitudinal collision had 12 o’clock PDoF (See Figure 2) [9].

The human factors used in the study were sex, age, and BMI. Age was classified into three groups to investigate the aging effect: <54 years, 55-64 years, and >65 years [10]. BMI was classified into three groups according to international standards: normal (18.5-24.9), overweight (25.0-29.9), and obese (>30.0) [11]. Underweight occupants were not considered in this study.

Vehicle type, crash object, seatbelt condition, and delta-V parameters were also used in the study for better analysis. The vehicles bigger than middle-size trucks were excluded from this study because the vehicle’s curb weights and structures were highly different. Consequently, sedan, sport utility vehicle (SUV), light truck, and van types of vehicles were only used. Crash object had two sub-categories, collisions with another vehicle and fixed objects. The occupants with fastened and unfastened seatbelts were separated. Occupants with fastened seatbelts used three-point and two-point belts. Delta-V parameter was estimated using PC-Crash software. The estimation confirmed checking the trajectory error during the reconstruction stage.

Statistical methodology
Statistical analysis was performed using the IBM SPSS statistics package 25. The mean, standard deviation, and statistical significance were analyzed using Pearson’s chi-square test and the independent sample t-tests. Statistical significance was set at p<.05. Risk factor analysis was performed by confirming the odds ratio and 95% confidence interval through binary logistic regression analysis. The probability of severe injury according to delta-V increase was analyzed in each oblique direction.

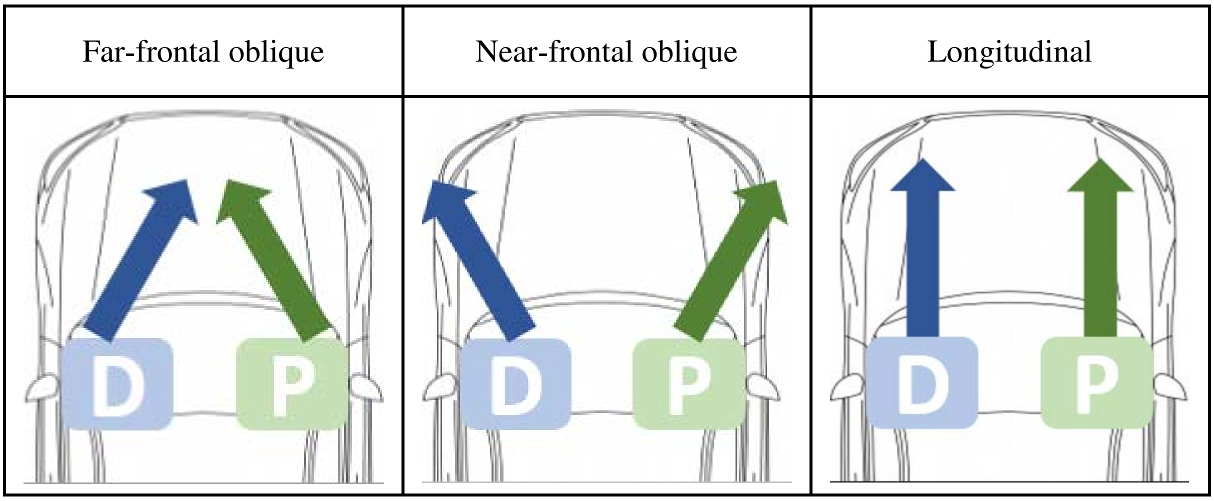

Figure 2. Oblique direction classification

RESULTS

Frequency analysis
The occupants in frontal collisions were classified into two groups according to thoracic injury severity (See Table 1). The rate of severely injured individuals was 17.4%. In the sex parameter, male occupants had a 31.8% higher frequency of thoracic injury than female occupants (p=0.004). The rate of severe injury increased in both 55-64 years and >65 years occupants (p=0.006). The occupants who belonged to the overweight or obese categories had a higher frequency of severe injury (p=0.010). The most common type of vehicle was a sedan. There was no frequency difference according to vehicle type (p=0.080). The number of driver occupants had around four times larger than the frontal passenger. The rate of severe injuries increased in the driver (p=0.004). The longitudinal direction was the most common in a frontal collision. The oblique direction had no frequency

Table 1.
General characteristics according to thoracic injury severity

Variables	Total (n=1,369)	Severe (n=238)	Non-Severe (n=1,131)	P-value
Sex, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Male	902 (65.9)	176 (73.9)	726 (64.2)	0.004
Female	467 (34.1)	62 (26.1)	405 (35.8)	
Age groups, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
<54 years	904 (66.0)	136 (57.1)	768 (67.9)	0.006
55-64 years	292 (21.3)	65 (27.3)	227 (20.1)	
>65 years	173 (12.6)	37 (15.5)	136 (12.0)	
BMI*, n (%).	(n= 1,369)	(n=238)	(n=1,131)	
Normal	1,026 (74.9)	160 (67.2)	866 (76.6)	0.010
Overweight	286 (20.9)	66 (27.7)	220 (19.5)	
Obese	57 (4.2)	12 (5.0)	45 (4.0)	
Vehicle type, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Sedan	783 (57.2)	130 (54.6)	653 (57.7)	
SUV**	258 (18.8)	43 (18.1)	215 (19.0)	0.080
Light truck	238 (17.4)	54 (22.7)	184 (16.3)	
Van	90 (6.6)	11 (4.6)	79 (7.0)	
Seating position, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Driver	1,077 (78.7)	204 (85.7)	873 (77.2)	0.004
Frontal passenger	292 (21.3)	34 (14.3)	258 (22.8)	
Oblique direction, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Far-frontal oblique	337 (24.6)	31 (13.0)	195 (17.2)	
Near-frontal oblique	226 (16.5)	60 (25.2)	277 (24.5)	0.277
Longitudinal	806 (58.9)	147 (61.8)	659 (58.3)	
Crash object, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Vehicle	965 (70.5)	166 (69.7)	799 (70.6)	0.783
Fixed	404 (29.5)	72 (30.3)	332 (29.4)	
Seatbelt, n (%)	(n= 1,369)	(n=238)	(n=1,131)	
Fastened	952 (71.1)	153 (65.9)	799 (72.2)	0.057
Unfastened	387 (28.9)	79 (34.1)	308 (27.8)	
Delta-V (kph), mean±S.D.***	30.42±21.68	36.91±21.47	28.91±21.46	<0.001

**BMI; Body Mass Index, **SUV; Sport Utility Vehicle, ***S.D.; Standard Deviation*

difference (p=0.227). Collisions with another vehicle accounted for about 70% of the total collision. However, the crash object parameter had no frequency difference (p=0.783). Around 71% of occupants fastened their seatbelts. Nevertheless, there was no frequency difference in injury severity (p=0.057). The delta-V had a 30.42 kph of mean value with a 21.68 kph of standard deviation. The delta-V mean value was about 6 kph higher in the severe thoracic injury group (p<0.001).

Risk analysis
Binary logistic regression analysis was performed to analyze the risk of severe thoracic injury. The analysis's parameters were the same as those used in the frequency analysis. However, vehicle type and crash object parameters were excluded because there were no significant differences. Although the oblique direction and seatbelt condition were not significant, they were included in the risk analysis because they were the main parameters of the study (See Table 2).

Female occupants had a smaller odds ratio (OR) than male occupants (OR=0.848). However, the significance of the sex parameter was over 0.05 (p=0.450). Age parameter showed that aging affected the risk of thoracic

Table 2.
A logistic regression analysis of severe thoracic injury risk

Parameter	OR**	95% CI***	P-value
Sex Male (ref)	1.000		
Female	0.848	0.553 – 1.301	0.450
Age <54 years (ref)	1.000		
55-64 years	1.819	1.192 – 2.777	0.006
>65 years	1.950	1.145 – 3.320	0.014
BMI* Normal (ref)	1.000		
Overweight	1.404	0.920 – 2.142	0.115
Obese	1.088	0.418 – 2.834	0.863
Seating position Driver (ref)	1.000		
Frontal passenger	0.465	0.271 – 0.797	0.005
Oblique direction Far-frontal (ref)	1.000		
Near-frontal	1.838	0.974 – 3.470	0.060
Longitudinal	1.879	1.053 – 3.354	0.033
Seatbelt Fastened (ref)	1.000		
Unfastened	1.394	0.961 – 2.022	0.080
Delta-V (kph)	1.018	1.010 – 1.026	<0.001

**BMI; Body Mass Index, **OR; Odds Ratio, ***CI; Confidence Interval*

injury. The occupants 55-64 years and >65 years had higher injury risk than <54 years adult individuals (p=0.006, p=0.014). In addition, The OR value of >65 years (OR=1.950) was higher than 55-64 years (OR=1.819). Occupants who belonged to the Overweight or obese group had higher OR than the normal group in the BMI parameter. However, there was no significance. Frontal passengers had a smaller OR than the driver (OR=0.465) with a significance under 0.05 (p=0.005). Longitudinal direction collision had a higher OR than the far-frontal direction (OR=1.879). It also had a significance under 0.05 (p=0.033). In contrast, the near-frontal direction had significance over 0.05 (p=0.060), and the OR value was 1.838 times higher than the far-frontal direction. Occupants with unfastened seatbelts had 1.394 times higher OR than occupants with fastened seatbelts. However, the significance of the seatbelt parameter was 0.080 so it was insignificant. The risk of a severe thoracic injury increased with an increased delta-V value (OR=1.018, p<0.001).

The binary logistic regression analysis showed the risk of severe thoracic injury in all frontal collisions. However, oblique direction and seatbelt parameters were insignificant. Therefore, further analysis was conformed dividing seatbelt conditions (See Table 3).

The risk of severe thoracic injury was analyzed using only occupants with fastened seatbelts. In the sex parameter, the OR of females was lower than that of males (OR=0.664). However, the significance was not confirmed (p=0.139). The OR for occupants aged 55-64 years was 1.857, the value was similar to that of the previous risk analysis. Also, the significance was under 0.05 (p=0.020). In contrast, the OR of occupants aged >65 years was 1.386, which was lower than the OR of the same parameter in the previous risk analysis. In addition, the significance was over 0.05 (p=0.354). BMI was not significant in both overweight and obese groups. The risk difference was not confirmed in the seating position parameter (p=0.176). All categories of oblique direction were identified as significant. The OR in the near-frontal direction was the highest at 2.964 (p=0.011). The OR in the longitudinal direction was 2.229 (p=0.050). The OR increased by 1.020 times as the delta-V value increased by 1 kph.

The risk of severe thoracic injury was analyzed using occupants with unfastened seatbelts. In the sex parameter, in contrast to the previous risk analysis, females had a higher OR than males (OR=1.327), but the significance was not confirmed (p=0.450). In the age parameter, the 55-64 years category was insignificant (p=0.133). However, significance was confirmed for occupants aged >65 years (p=0.011). The OR of occupants aged >65 years was 3.163, which was higher than the value of the same category in the previous risk analysis. In the BMI parameter, both the overweight and obese groups had a higher OR than the normal group. However, both sub-

Table 3
A logistic regression analysis of severe thoracic injury risk according to seatbelt parameter

Parameter	OR**	95% CI***	P-value
Seatbelt Fastened			
Sex Male (ref)	1.000		
Female	0.664	0.386 – 1.143	0.139
Age <54 years (ref)	1.000		
55-64 years	1.857	1.103 – 3.127	0.020
>65 years	1.386	0.694 – 2.767	0.354
BMI* Normal (ref)	1.000		
Overweight	1.310	0.783 – 2.192	0.304
Obese	0.293	0.037 – 2.335	0.246
Seating position Driver (ref)	1.000		
Frontal passenger	0.617	0.307 – 1.241	0.176
Oblique direction Far-frontal (ref)	1.000		
Near-frontal	2.964	1.282 – 6.852	0.011
Longitudinal	2.229	1.000 – 4.970	0.050
Delta-V (kph)	1.020	1.010 – 1.030	<0.001
Seatbelt Unfastened			
Sex Male (ref)	1.000		
Female	1.327	0.636 – 2.768	0.450
Age <54 years (ref)	1.000		
55-64 years	1.794	0.838 – 3.843	0.133
65 years over	3.163	1.296 – 7.718	0.011
BMI* Normal (ref)	1.000		
Overweight	1.540	0.716 – 3.310	0.269
Obese	2.789	0.824 – 9.445	0.099
Seating position Driver (ref)	1.000		
Frontal passenger	0.278	0.112 – 0.688	0.006
Oblique direction Far-frontal (ref)	1.000		
Near-frontal	0.623	0.202 – 1.919	0.409
Longitudinal	1.498	0.628 – 3.571	0.362
Delta-V (kph)	1.014	1.011 – 1.028	0.034

**BMI; Body Mass Index, **OR; Odds Ratio, ***CI; Confidence Interval*

parameters were not statistically significant. The OR of the frontal passenger was 0.278, indicating a lower risk of thoracic injury than the driver (p=0.006). The oblique direction had no statistical significance in all sub-parameters. In contrast to the previous risk analysis, the OR of the near-frontal direction decreased. The OR increased by 1.014 times as the delta-V value increased by 1 kph (p=0.034).

Each oblique direction was independently classified, and the age-related probability of severe thoracic injuries was analyzed based on the increase in delta-V.

The probability of severe thoracic injury was confirmed for occupants with fastened seatbelts (See Figure 3). As delta-V increased, the probability of severe injury increased rapidly in the following order: near-frontal, longitudinal, and far-frontal. Occupants with <54 years of age had the lowest probability of severe thoracic injury in all oblique directions. The same analysis was conducted for occupants with unfastened seatbelts (See Figure 4). In this analysis, the probability of severe injury was increased in the following order: longitudinal, far-frontal, and near-frontal. In all oblique directions, the probability of thoracic injury for occupants was higher in the order of >65 years, 55-64 years, and <54 years.

Far-frontal	Near-frontal	Longitudinal

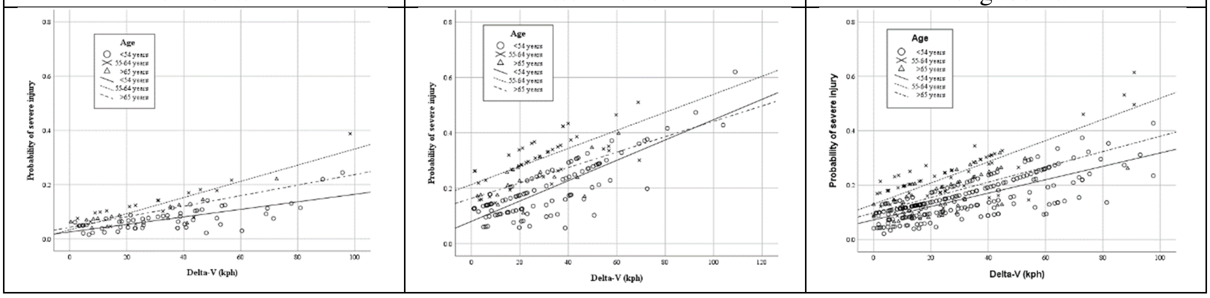

Figure 3. Probability of age-related thoracic injury for occupants with fastened seatbelts

Far-frontal	Near-frontal	Longitudinal

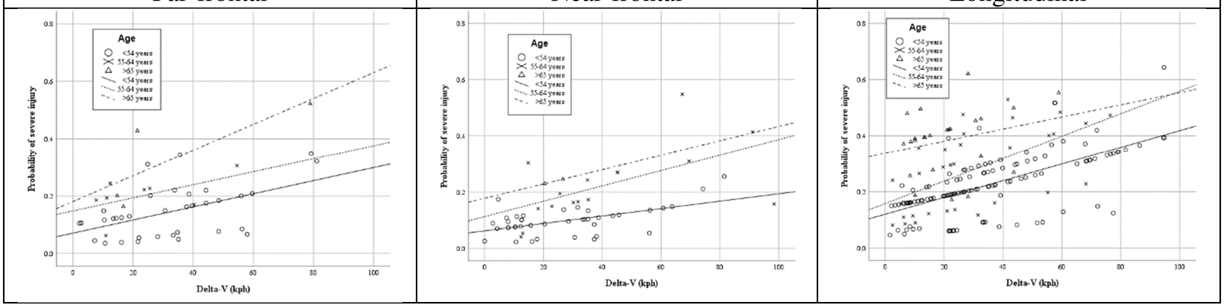

Figure 4. Probability of age-related thoracic injury for occupants with unfastened seatbelts

DISCUSSION

This study confirmed statistical differences in the risk of severe thoracic injuries in frontal oblique collisions according to age and oblique direction. Injury severity was classified in AIS3. Examples of thoracic injuries corresponding to an AIS score of 3 include multiple rib fractures, vascular injury, lung injury, and hemothorax. These AIS3+ injuries are regarded as severe because they may result in death or insufficient recovery [12]. In particular, the thorax is a structurally important region of the human body that contains various portions, including major organs, blood vessels, and skeletons [13].

As a result of frequency analysis according to the severity of the thoracic injury, the parameters that confirmed the significance were sex, age, BMI, seating position, and delta-V. Vehicle types and crash object parameters were not significant and were excluded from further risk analysis. Vehicle types were classified based on the shape of the vehicle, but additional factors such as the vehicle's curb weight were not considered. In the future, it is necessary to conduct research by classifying vehicles in more detail [14]. The crash object parameter was limited to the case of a collision with another vehicle or a fixed object. However, the pole-type object was excluded from this study. It is an important parameter, but most of the occupants engaged in pole injuries belong to the longitudinal direction. Also, in the case of a vehicle-to-vehicle collision, the difference in curb weight and shape between the two vehicles was not considered. These limitations need to be overcome by subdividing vehicle-to-vehicle collisions using globally reliable classification criteria.

Age was classified into three groups. The standard for seniors is 55 years old and the standard for the elderly is 65 years old, which is globally used [10,15]. In this study, it was confirmed that older occupants were more vulnerable to thoracic injuries. However, there were some unclear results due to the lack of elderly occupants' data. Previous research has shown a similar result that age has a significant impact on the injury severity of the thorax [16,17].

The oblique direction was classified into three groups considering PDoF and seating position. In the frequency analysis, the oblique direction had not shown an injury severity difference in the thoracic region. However, the risk difference was confirmed for each oblique direction. the occupant's seatbelt conditions made these risk differences among the oblique directions. In the analysis using occupants with fastened seatbelts, the injury risk of near-frontal direction was found to be the greatest. The near-frontal direction of the three-point seatbelt was found to have the lowest occupant protection efficacy in previous research [9,18]. Additionally, the near-frontal direction was found to have the greatest increase in the risk of severe injury with an increase in delta-V. Significance according to the oblique direction was not confirmed using the occupant with unfastened seatbelts condition. According to this analysis, the longitudinal direction showed the highest increase in the risk of severe injury due to an increase in delta-V. The risk of thoracic injury was confirmed to be increased in the far-frontal direction than in the near-frontal direction. Previous research suggests that the risk of severe thoracic injury increased when occupants did not fasten their seatbelts in a frontal oblique collision [19]. However, the delta-V was not considered in that study. Furthermore, the result is limited to the near-frontal oblique direction and the driver position. Because of the shortage of studies on the far-frontal oblique direction, an in-depth study on the oblique direction according to individuals without seatbelts must be done in the next studies [17].

The frequency of male occupants was higher in the severe group. However, there was no significance in the risk of severe thoracic injury according to sex parameter. Previous studies have shown that male occupants have a higher risk of severe injury than female occupants [20]. However, the sample size of the study is about 100 times different from that of this study. Occupants of overweight and obese groups were found to have a higher risk of severe thoracic injuries than normal groups. However, no significant difference was observed among sub-parameters of BMI for the risk of severe injury. Previous research has shown that individuals that belonged to overweight or obese BMI are more vulnerable to thoracic injuries than normal BMI groups [21].

CONCLUSIONS

In this study, the aging effect of occupants affects to the risk of severe thoracic injury. The oblique direction also affected the risk of severe injury. However, the significance of risk due to oblique direction was limited only to occupants with fastened seatbelts. The risk of severe injury to occupants with unfastened seatbelts was the highest in the longitudinal direction. However, the research on unfastened seatbelt condition had not sufficient. This study showed the detailed risk of the thoracic region using the real-world collision database. The research could be used to enhance occupant safety and advance the crashworthiness of vehicle structures.

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