THORACIC INJURY CHARACTERISTICS OF ELDERLY DRIVERS IN REAL WORLD CAR ACCIDENTS

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ABSTRACT

Recent research has indicated that elderly occupants are more vulnerable than other age groups in motor vehicle crashes while the elderly population has significantly grown worldwide. Based on the comprehensive claim data (2000-2008) from an automobile insurance company in South Korea, the survey showed that elderly drivers (65+) suffer thoracic injuries more compared to the other age groups. To show the significance of the age effect, this study investigates injuries among the different age groups involved in frontal, side and rear collisions based on real world crash data.

Real world crash analysis was statistically performed to analyze the elderly driver's accident pattern, and injury types in a variety of impact crashes. The result shows the thoracic injury risk of the elderly group is 2.6 times higher than that of the middle age group (24-54) in frontal crashes, 2.7 times in side crashes, and 4.8 times in rear crashes. In-depth study was conducted to compare the degree of injuries in detail between elderly drivers and non-elderly drivers. The medical records showed that elderly drivers have higher possibility of the thoracic injury. Diagnosis shows that most of thoracic injuries were caused by rib fractures. It has been demonstrated elderly drivers are likely to suffer more injuries at a chest region compared to the middle-aged group. Finally, thoracic injury analysis of two cases was done using CT images of injured elderly drivers. Using the reconstruction software, 3D model was built to analyze injury characteristics accurately. This model provided the detailed trace on rib fractures and showed the cause of injuries were safety devices such as seat belt and airbag. This research calls attention to the need for design improvement to make vehicles more protective for older drivers in car-to car frontal crashes.

INTRODUCTION

South Korea became an aging society in 2000 and has been changed to an aged society very fast. Therefore, it is natural that automotive accidents involving elderly occupants have also increased continuously. Consequently, the injuries of the elderly in motor vehicle crashes is a serious concern. According to the Traffic Accident Statistics in 2009, 1,735 people age 65 and older were killed in 2008, and these older individuals made up 29.6% of all traffic fatalities. Compared to 2007, all accidents increased by 2.0% but the accidents involving elderly people increased by 8.9%. Among people injured in this age group there was a 8.9% increase from 2007. Figure 1 shows the increase of the accidents involving the elderly from 2005 to 2010.

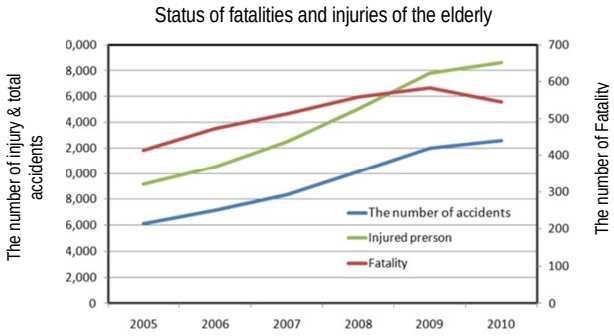

Figure1. The number of elderly drivers in traffic accidents in South Korea

Previous studies have shown that one of the most important factors that affect a person's risk of injury in a motor vehicle crash is the age of the occupant. Schmidt (1971) presented the difference of the degree of thoracic injuries by age performing crash tests at 40 km/h involving cadavers in twenties and sixties. Neathery (1974) and Marcus (1983) showed the result that AIS level of thoracic injury increases 0.31 and 0.25 respectively when people get old.

Zioupos (1998) concluded the aging induced the weakness of structure and mechanical property of bone and consequently, the elderly can be injured easily with the similar impulse. Carpo (1998) announced the rib cage of older people becomes harder. Kent (2005) analyzed the NASS-CDS and FARS concluded that 47.3% of the elderly group were killed due to the thoracic injury compared to 24.0% of mid-aged group. NHTSA (2007) followed the statistical data about frontal crashes in NASS-CDS from 1993 to 2004 and announced thoracic injuries of the elderly were doubled than that of the non-elderly that in frontal crash. Especially, among the cases with MAIS 4, thoracic injuries rank second to head injuries. Kent (2005) also reported that not only the thoracic shape but also the material property of bones is the major element by examining the reconstructed CT images. NHTSA (2009) continued to study thoracic injuries among older motor vehicle occupants. In this study, NASS-CDS for the years 1998 to 2007 was used to measure the relationship between occupant's age and the incidence of thoracic injuries. It demonstrated that the age group 75 and older (75+) had a higher percentage of AIS moderate or more sever (2+) thoracic injuries when driving or riding in any passenger vehicle type compared to three other age groups in a tow-away crash. Hong et al. showed the injury characteristics of the Korean elderly based on real world crash data in frontal, lateral, and rear impact, and reported thoracic injury is the most vulnerable to the elderly drivers. Stitzel (2010) attempted the first quantitatively estimated mortality age thresholds for common isolated thoracic injuries through the receiver-operator characteristic analysis based on the data of selected AIS 3+ thoracic injuries in NASS-CDS (2000-2008).

The objective of this research is to provide the information on injury characteristics of Korean elderly drivers in real world car accidents through the analytical and integrated approach in Figure 2.

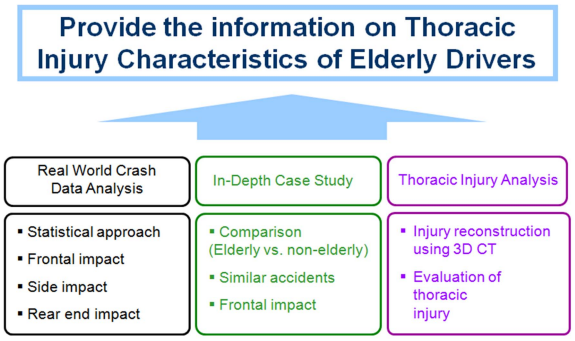

Figure2. Scope of this study

METHODS

While previous researches focus mainly on figuring out the differences of an occupant injuries by age, crash type, injury type, etc based on the database, this research focused on performing the in-depth study more in detail by comparing several pairs of similar real world accidents involving the elderly and the non-elderly drivers in the same accidents in terms of vehicle model, crash type, severity, and damage. Moreover, the examination of thoracic injury characteristics was made using CT images.
In this study, there are three progress made:

- Real world crash data analysis
- In-depth case study
- Thoracic injury analysis

Firstly, the claims from an automotive insurance company in South Korea for the years 2000 to 2008 were statistically investigated to analyze the relationship between occupant's age and the incidence of the injuries in the different accident types such as frontal, side, and rear collisons. Secondly, several pairs of similar frontal impact accidents were extracted from the data source with respect to vehicle model, crash type, restraint device, and vehicle damage. The related medical treatment records were also reviewed and matched to severity and vehicle damage.
Finally, the thoracic injuries of the elderly driver were analyzed by reconstructing CT images to 3D model.

Real world crash data analysis

Based on the comprehensive claim data (2000- 2008) from an automobile insurance company in South Korea, the statistical analysis was conducted to investigate the injury trend on the elderly group compared to the other age group. Total 65,126 cases in three crash directions were included according to the following criteria from 2000 to 2008; frontal (26,057 cases, 2000-2007), side (5,583 cases, 2007-2008), and rear (33,486 cases, 2000-2008).

- car-to-car (except multiple crashes)
- sedan and sport utility vehicle
- not minor vehicle damage

Age groups under 24, 24 to 54, 55 to 64, and over 65 were compared by body region. Z-test was done to verify significance level.

In-depth case study

Among the database in the statistical analysis above, some cases were extracted with respect to vehicle model, damage type, and driver's age. And each case was collected by analyzing the accident reports. For the in-depth real world crash analysis, the specific cases were extracted from the previously collected dataset as following criteria;

- same target vehicle
- similarity of CDC code and delta-V
- comparative driver(elderly and non-elderly) in the same vehicle model

CDC (Collision Deformation Classification) and AIS (Abbreviated Injury Scale) were used as a measurement of the depth of vehicle damage and occupant's injury respectively.

Thoracic injury analysis

Generally, two-dimensional CT (Computer Tomography) images are used to analyze the injury of internal organs and hemorrhage, but are not accurate and limited to investigate bone fractures in detail. Therefore, three-dimensional reconstruction method is utilized to recreate 3D computer model from 2D CT images. By looking into the trace that rib fractures occurred, the cause of injury can be inferred.

In this study, the further investigation on injury characteristics was conducted using MIMICS (3D reconstruction software) with CT images of the elderly patients in car accidents as shown in Figure 3.

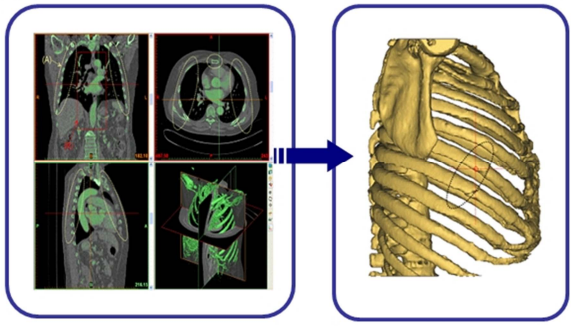

Figure3. 3D Reconstruction of rib fractures using CT images

RESULTS

Real world crash data analysis

Frontal collisions Figure 4 shows the distribution of the normalized injury incidence rate by body region. Assumed that the number of injuries of the middle age group between 24 and 54 is 1.0 as relative index, the numbers of injuries of the other age group were normalized. Distribution of normalized index in Figure 4 means the similar incidence rate in most of body parts except in thorax. The age effect caused about 2.6 times possibility of thoracic injury of elderly occupants.

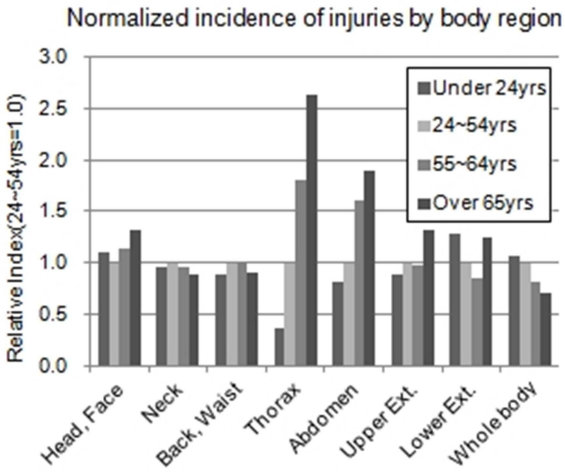

Figure4. Normalized incidence of injuries in frontal collisions

Injury severity of the thorax was also reviewed in Figure 5. Both MAIS2- and MAIS3+ injuries also increase as a driver gets old and the increase of the incident rate of MAIS3+ injuries is much higher than MAIS2- between 24-54 age group and 65+ age group.

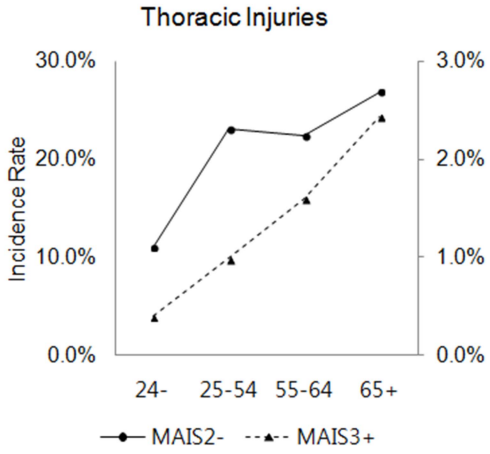

Figure5. Increase of thoracic injury severity in frontal crashes by age (p-value < 0.05)

Side collisions Similarly in frontal collisions, the incidence rate of thoracic injuries of elderly drivers is about 2.6 times than that of 24-54 year-old drivers as shown in Figure 6.

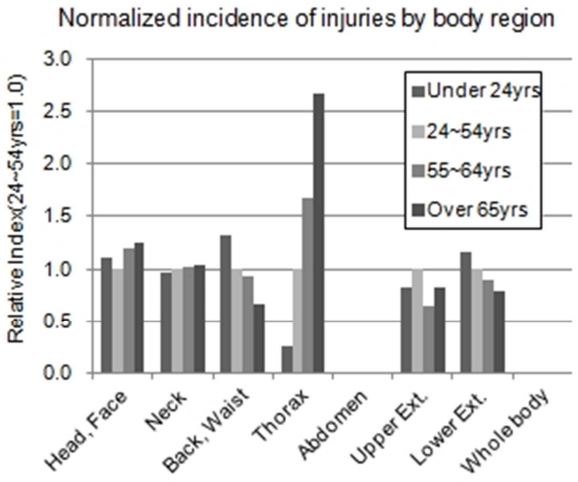

Figure6. Normalized incidence of injuries in side collisions

Different from the incidence rate in frontal crashes, MAIS3+ injuries has a significant increase from 17% to 50% while MAIS2- under 1.2%. This demonstrated when lateral crashes occur, the thoracic injury of the elderly driver become severe.

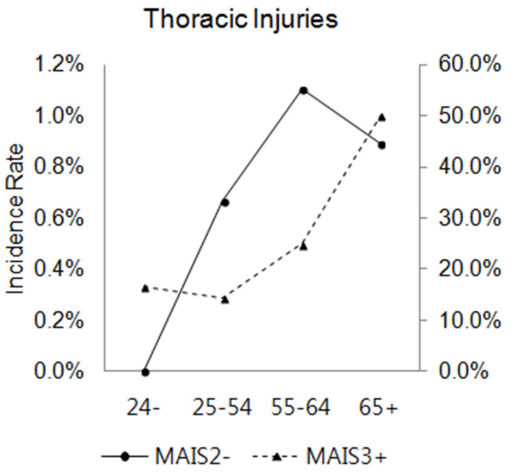

Figure7. Change of thoracic injury severity in side crashes by age (p-value < 0.05)

Rear collisions In rear collisions, the age effect doesn't show the significance except thorax. Relative index shows most of injuries in other body parts are similar while thoracic injuries get much higher by 4.7 times. Over 55 year-old drivers is much vulnerable to the thoracic injuries.

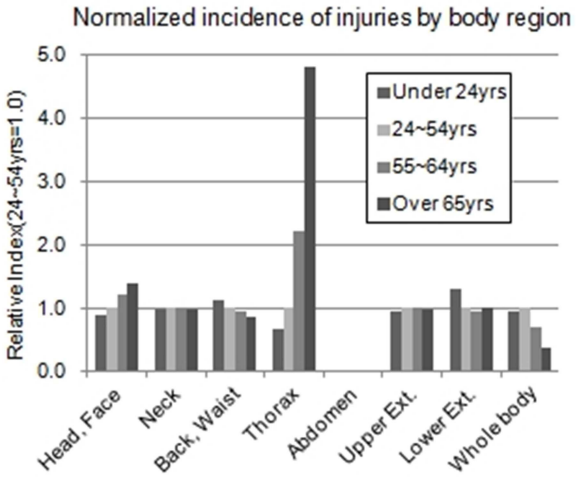

Figure8. Normalized incidence of injuries in rear collisions

In Figure 9, the incidence rate of MAIS2- thoracic injuries is very low (under 1%), however, that of MAIS3+ thoracic injuries go up to 22% from 7%.

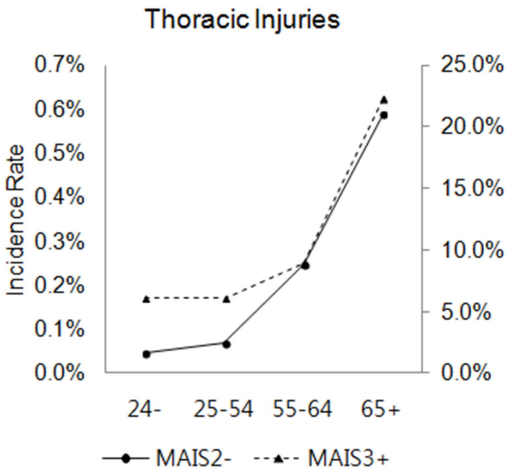

Figure9. Change of thoracic injury severity in rear crashes by age (p-value < 0.05)

In-depth case study

In this step, thoracic injuries in frontal collisions were considered. Table 1 presents the general information of vehicles (vehicle type, vehicle damage type) and drivers (age, sex, airbag deployment, major injured body region, maximum AIS, hospitalization period). Overall, the most severe injury of 5 elderly drivers was thoracic

injuries with rib fractures (MAIS3+) in all cases while other drivers suffer minor neck injuries or no injury. All occupants wore seat belts and airbag was deployed in only case 4.

Table1.
Information of vehicles and drivers used in the in-depth case study

No	Type	CDC	Age	Sex	Airbag	Body	MAIS	Period*
1	Sedan	12FDEW3	65	M	×	Thorax	3	43
			42	M	×	Neck	1	25
2	Sedan	01FREW2	65	M	×	Thorax	3	45
			57	M	×	Neck	1	6
3	SUV	12FDEW2	67	M	×	Thorax	3	107
			33	M	×	None	0	0
4	Sedan	01FREE2	66	M	○	Thorax	1	8
			22	M	○	None	0	0
5	Sedan	11FLEE3	70	M	×	Thorax	2	17
			47	M	×	Neck	1	11

* Hospitalized period
** All drivers were buckled.

Case 1 Two small sedans were impacted in a longitudinal direction and got similar damages as seen in Figure 10. Two sedans have 12FDEW3 CDC code

Figure10. Comparison of vehicle damage (Case 1)

Table 2 presented the detailed injury type and severity by body part. There were multiple rib fractures with lung contusion in thorax and liver and skin contusion in abdomen. Maximum AIS was 3 of the older driver in Case 1. However, there were multiple minor injuries (MAIS 1) in face, spine, upper and lower extremities reported for the younger driver in the similar accident.

Table2.
Medical records in Case 1 (65 year-old driver vs. 42 year-old driver)

Driver's age: 65 year-old		
Body	Injury	AIS
Thorax	Rt. Multiple Rib Fr. with Flail	450211.3
Thorax	Rt. Hemothorax	442200.3
Thorax	Lung Contusion	441402.3
Abdomen	Liver Contusion	541810.2
Face	Skin Multiple Laceration	210600.10553
Face	Rt. Eyelid Laceration	210600.10155
Abdomen	Skin Contusion	510402.1

Driver's age: 42 year-old		
Body	Injury	AIS
Face	Skin Contusion	210402.1
Face	Skin Abrasion	210202.1
Spine	Neck Spine Strain	640278.1
Upper Ex	Rt. Hand Skin Contusion	710402.1
Upper Ex	Rt. Hand Skin Abrasion	710202.1
Lower Ex	Knee Joint Sprain	874010.1
Lower Ex	Knee Contusion	810402.1
Lower Ex	Knee Abrasion	810202.1

Case 2 In Case 2, there was 91FREW2 CDC code in each sedan, and likewise the older driver had MAIS 3 injury in thorax while the younger driver minor contusion in head and spine.

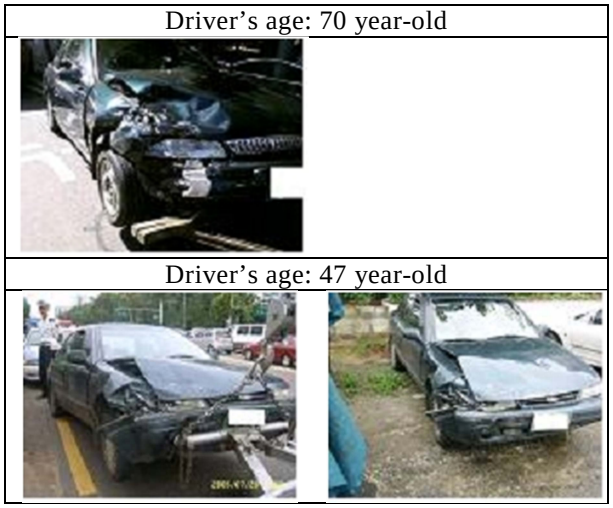

Figure11. Comparison of vehicle damage (Case 2)

Table3.
Medical records in Case 2 (70 year-old driver vs. 47 year-old driver)

Driver's age: 70 year-old		
Body	Injury	AIS
Thorax	Rt. 8-10 Rib Fractures	450203.3
Lower Ex	Pelvic Ring Fracture	856161.3

Driver's age: 47 year-old		
Body	Injury	AIS
Head	Cerebral Concussion	161000.1
Spine	Neck Spine Strain	640278.1
Spine	Lumbar Spine Strain	640678.1

Case 3 Figure 12 and Table 4 presented CDC code was 12FDEW2 in SUV and the older driver suffered from MAIS 3+ cerebrum contusion, rib and sternum fractures. However, the younger driver didn't get any injury.

Figure12. Comparison of vehicle damage (Case 3)

Table4.
Medical records in Case 3 (65 year-old driver vs. 57 year-old driver)

Driver's age: 65 year-old		
Body	Injury	AIS
Head	Cerebrum Contusion	140602.3
Thorax	Rt. 3-4 Lt 1 Rib Fractures	450203.3
Thorax	Sternum Fracture	450804.2
Spine	4-5 Neck Disc Herination	650200.2
Spine	6-7 Neck Disc Bulging	650299.2
Spine	Lumbar Spine Strain	640678.1

Case 4 In each accident, both drivers were protected by airbags that mitigated the injuries (Figure 13 and Table 5). Therefore, the older driver got MAIS 1 thoracic and neck injury and the younger got no injury.

Figure13. Comparison of vehicle damage (Case 4)

Table5.
Medical records in Case 4 (67 year-old driver vs. 33 year-old driver)

Driver's age: 67 year-old		
Body	Injury	AIS
Thorax	Rt. 9 Rib Fracture	450201.1
Spine	Neck Spine Strain	640278.1

Case 5 Figure 14 and Table 6 shows another example of thoracic injuries of the elderly.

Figure14. Comparison of vehicle damage (Case 5)

Two vehicles were impacted in 11 o'clock direction with 11FLEE3 in Figure 14. Table 5 showed that the older driver got sternum fracture (MAIS 2) and minor contusion. The younger driver got neck spine strain (MAIS 1).

Table6.
Medical records in Case 5 (66 year-old driver vs. 22 year-old driver)

Driver's age: 66 year-old		
Body	Injury	AIS
Thorax	Sternum Fracture	450804.2
Spine	Neck Spine Strain	640278.1
Upper Ex	Rt. Skin Contusion	710402.1
Whole	Multiple Skin Contusion	910400.1

Driver's age: 22 year-old		
Body	Injury	AIS
Spine	Neck Spine Strain	640278.1
Spine	Lumbar Spine Strain	640678.1
Lower Ex	Rt. Cruciate ligament Sprain	874010.1
Lower Ex	Rt. Knee Contusion	810402.1

Thoracic injury analysis

In this step, the further study was performed to clarify the cause of rib fractures of the elderly drivers from the in-depth study by examining 3D model reconstructed by Mimic software using CT images.

Case 1 Figure 15 shows vehicle damage in Case 1. Mid-size sedan (MY07) was crushed in car-to-car collisions and airbag was deployed. The belted elderly driver (69 year-old man) was injured as indicated in Table 8. By examining 3D reconstruction of CT images, the cause of injury was found that his sternum and ribs were fractured along seat belt line.

Figure15. Vehicle damage (Case 1)

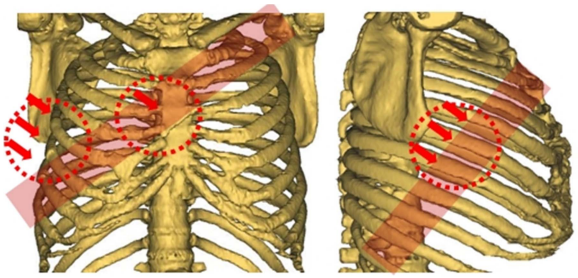

Figure16. 3D model of thoracic CT images (injured by seat belt)

Table7.
Medical records (69 year-old driver)

Driver's age: 69 year-old		
Body	Injury	AIS
Thorax	Rt. 5-7 Rib Fractures	450203.3
Thorax	Rt. Hemothorax	442200.3
Thorax	Sternum Fracture	450804.2

Table8.
Evaluation of injury severity using 3D model of thoracic CT images (69 year-old driver)

Positoin	Severity	Evaluation
Sternum	serious	AIS 3
R5	moderate	
R6	serious	
R7	serious	

Case 2 Another case is presented that SUV was damaged (Figure 17) and 75 year-old male was injured in a driver's side (Figure 18 and Table 9). He was belted and airbag was deployed. As shown in Table 10, the examination of 3D model of thoracic CT images gives the description that how rib fractures occurred and that what's the source (airbag and seat belt). 3D model provided more detailed injury characteristics of each rib cage.

Figure17. Vehicle damage (Case 2)

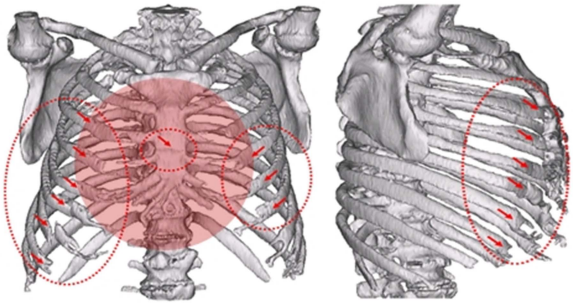

Figure18. 3D model of thoracic CT images (injured by airbag and seat belt)

Table9.
Medical records (75 year-old driver)

Driver's age: 75 year-old		
Body	Injury	AIS
Thorax	Rt. 3-8, Lt. 4-9 Rib Fractures	450203.3
Thorax	Hemothorax	442200.3
Thorax	Sternum Fracture	450804.2
Abdomen	Liver Laceration	541822.2
Lower Ex	Rt. Knee Laceration	810600.1

Table10.
Evaluation of injury severity using 3D model of thoracic CT images (75 year-old driver)

Positoin	Severity	Evaluation
Sternum	minor	AIS 3
R3	moderate	
R4	serious	
R5	serious	
R6	severe	
R7	severe	
R8	moderate	
L4	minor	
L5	moderate	
L6	moderate	

CONCLUSIONS

Through three approaches using real world crash data analysis, in-depth case study, and thoracic injury analysis, this research concluded the relationship between age and the incidence of thoracic injuries in various crash accidents as following.

(1) Thorax is the most vulnerable body region of elderly drivers. The possibility is 2.6 times higher in frontal and side impact, and 4.8 times in rear end impact.

(2) In frontal crashes, MAIS2+ thoracic injuries are prevalent (10% for under 24 age group, 27% for over 65 age group) compared to MAIS3+ (4% for under 24 age group, 2.4% for over 65 age group). Obviously, head and neck injuries are still dominant in frontal impact no matter how a driver is old, but as a driver is older, it is remarkable that the percentage of thoracic injury becomes doubled.

(3) In lateral and rear end crashes, MAIS3+ thoracic injuries increase significantly as a driver get older (up to 50% in side, 23% in rear).

(4) Total ten cases were further examined to figure out the difference of injuries of the elderly and the non-elderly in the same accidents in detail one by one. In all cases, the elderly drivers suffered from neck and thoracic injuries together while non-elderly drivers suffered from neck injuries or had no injury.

(5) 3D reconstruction using CT images was attempted for two cases in this study. 3D model can provide more detail trace or imprint of the impact exerted on rib cage. This can provide what is the source of injury accurately. Even this method is useful; the quantitative and qualitative measurement should be developed continuously.

(6) 3D model of thoracic injury can be used to evaluate and validate computational human dummy model.

(7) Seat belt and airbag should be designed to improve the protecting capability of reducing thoracic injuries in frontal collisions. For example, it can be possible by controlling the load limiter of seat belt, airbag pressure and timing, etc.

(8) Evaluation of the performance of restraint systems for the elderly should be developed as the old population grows rapidly

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