# A STUDY OF THORACIC INJURY CRITERIA FOR ELDERLY KOREAN OCCUPANT

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## ABSTRACT

According to 2005 national census, more than 65 year older population is about 10% of total 48millions population. In 2030, the elderly rate will be reached up to 23%. The statistical analysis of elderly traffic accident from the national policy report, the elderly fatalities was 2,183 (33.3% of 6,563) in 2004. This was the double increase compared with 14 year years ago. In 1994, elderly fatality was 1,748 (17.3%). Elderly driver and passengers have a disproportionately higher crash involvement rate and commonly sustain more severe injuries than the other generation.

The current frontal impact regulation of Korean safety standard (KMVSS 102) is based on the FMVSS 208 to protect the motor vehicle occupant in the event of frontal crash type accidents. The injury criteria utilized in the regulation is based on 50%tile Hybrid III dummies in both driver and passenger sides. Therefore, no motor vehicle standards in Korean are designed to specially address the needs of elderly persons. Since the elderly population is rapidly increasing, it is more important to improve the safety standard to mitigate elderly casualties.

A primary objective of the study is to develop a guideline or standard for elderly occupants protection with new injury criteria on the frontal impact regulation and to promote design of restraint system or so call silver vehicle for elderly in the domestic market. The physical characteristics of elderly Korean occupant are relatively small and lighter than that of western elderly. Data from the SizeKorea database (total surveyed number of subjects in SizeKorea database was 14,200 between 0 to 90 years old), the 50th %tile height and weight of the subjects in target group (527 male samples) were 162.8cm and 62kg, respectively.

From the in-depth study of recent years vehicle-to-vehicle frontal crash accidents, the elderly occupant sustain more thorax rib fracture injury within MAIS <2. More than MAIS >3 case, elderly suffers more hemo/pneumo thorax injury than younger occupant.

In this study, as an assessment tool with scaling methods 50%tile Korean elderly Hybrid III type

simulation model was developed to mitigate elderly thorax injury.

## INTRODUCTION

Each nation has it's own vehicle safety standard as a regulation to protect the peoples. Therefore, a vehicle must meet the requirements of specific safety standards as minimum requirements such as structural performances and occupant protections. For assessing the occupant protection of the vehicles, the various types of standardized Anthropomorphic Test Devices (ATDs) are used. The first regulation utilizing full scale frontal crash testing of vehicles with test dummies is the FMVSS 208 in 1973. The crash test dummy used was the Hybrid II dummy, developed by General Motors in 1972, mainly to assess the integrity of lap and shoulder belt restraint system. Hybrid III dummy has the size, shape and mass distribution of a 50th percentile American adult male. Currently, world-widely using new dummy called the Hybrid III, was developed by G.M. with substantial improvement in biofidelity over the Hybrid II dummy in all parts of the dummy. In 1984, the Hybrid III dummy has become the only dummy that can be used for compliance purposes. Frontal Crash Regulations in Korea has also accepted the Hybrid III dummy as the test device with controls over the measured dummy responses.

Beside as a regulation tool, the dummy can be used as a Occupant injury assessment tools to research and development of advanced occupant restraint systems. Traditionally, Anthropomorphic Test Devices (ATDs) have been used in laboratories to evaluate the restraint system performance with built-in various types of sensors attached in the most frequently injured body parts such as head, neck, chest, femur and lower extremity.

In Korea, the occupant protection standard for the frontal crash test is KMVSS 102. In the regulation, Hybrid III 50%tile dummies are used to assess the safety of a vehicle.

From 2000 national census, the population of 65 year and more (65+) was reached 3.4 million (7.2%) and entered aging society. Due the current extremely lower birth rate, the aging rate is rapidly increased. The most demographic forecasts indicate the proportion of Korean over 65 years of age by the year 2019 will be more than 14% of total population as a aged society. Therefore, it will become increasingly more important that safety standards be optimized to mitigate elderly casualties. Currently, no motor vehicle safety standards in Korea are designed to specifically address the needs of elderly persons. Elderly drivers and passengers have a disproportionately higher crash involvement rate and commonly sustain more severe injuries than the general population. From the National Police Reported Accident Data for the years 1994 to 2006, the fatality of the age group 61 and older (61+) was continuously increased 1,748 (17.3%) to 2,136 (33.8%). Still, the majority of elderly fatality is coming from the pedestrian casualty, however, the fatalities of elderly occupants (driver or passenger) is continuously increasing year by year.

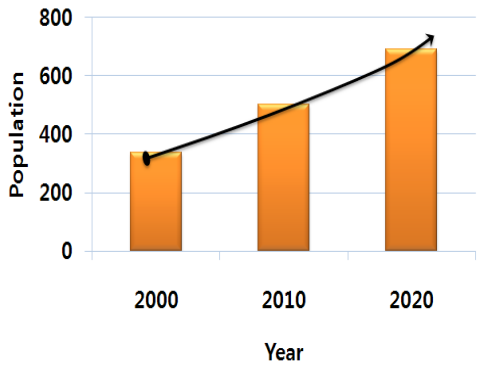


**Figure 1. Elderly Population in Korea.**

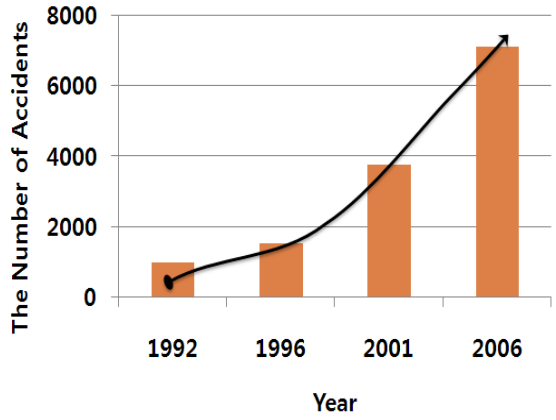


**Figure 2. The Number of Korean Elderly Involved in Accidents.**

Therefore, providing mobility as well as improvement of safety for older occupants is essential for aging society by the means of development of older occupant friendly vehicle. NHTSA launched "Safer Mobility for a Maturing Society: Challengers and Opportunities" program in 2003. The program shows the target and strategic plans for older drivers and pedestrian to promote safer mobility. Due to the global trend of the societal aging with more than 20% of elderly population, auto manufactures in the advanced nations such as US and Japan concentrate their endeavors on the development of the technologies for the elderly friendly vehicle. The research group includes Korean government (MLTM) and domestic auto makers are putting their enormous efforts to develop key technologies for the elderly friendly vehicle. In the project, the target was set for the comfort and safety improvements of the transportation with vulnerable people, preparing the aging society, consists of the following 5 categories that will provide a safe and convenient transportation to elderly population and also comfort ingress and egress (boarding and un-boarding) to the disabled.

To provide the safety for the elderly occupants, it will be necessary to review the safety standards to mitigate elderly casualties. Currently, the injury criteria in KMVSS are determined by Hybrid III 50%tile dummy readings similar to other countries. In the project, the best suitable injury criteria for Korean elderly occupant will be developed. It is almost impossible to develop a physical Korean elderly dummy to assess the injury mitigating performance of the so called "elderly friendly vehicle" and the restraint system. Since the Hybrid III 50%tile male dummy is only the dummy regulatory body accepted, the main objective of the research is focus developments of converting table or equation. This scale method will be convert Hybrid III 50% dummy tested injury values to the Korean elderly injury values.

In this paper, the traffic accident patterns and injury types of elderly occupants suffered are examined and analyzed using the insurance company database. To investigate the converting equation, the standard 50%tile Korean elderly Hybrid III model is developed by scaling method in MADYMO model.

## INJURY CHARACTERISTICS OF ELDERLY OCCUPANTS

### Literature Survey

Although older drivers are involved in relatively few collisions due to limited exposure, once involved in a crash they are more likely to sustain severe injuries or death. Several studies have confirmed that as people age, they are more likely to sustain serious or fatal injuries from the same severity crash (Evans, Evans, Bedard *et al.*, Mercier *et al*). Elderly drivers

and occupants are especially at risk of thoracic region injuries due to increased bone fragility (University of Michigan, Wang *et al*., Wang, Augenstein *et al*., Foret-Bruno, Schiller, Sjogren *et al*., Bulger *et al*.). Currently, no motor vehicle safety standards in Canada are designed to specifically address the needs of elderly persons. Results from S.C Wang, the head injury is the most frequent in younger age group, while the older age group is suffered from mostly thoracic injury as shown in Figure 3. It is clearly show that in the Figure 4, the older age group, the more numbers of rib fracture is occurred in the frontal collision.

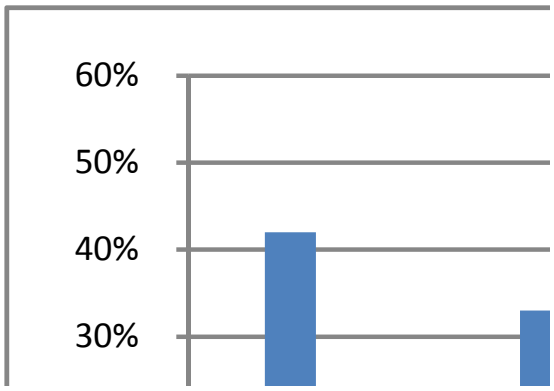


**Figure 3. Incidence of Thoracic and Head Injury by Age.**

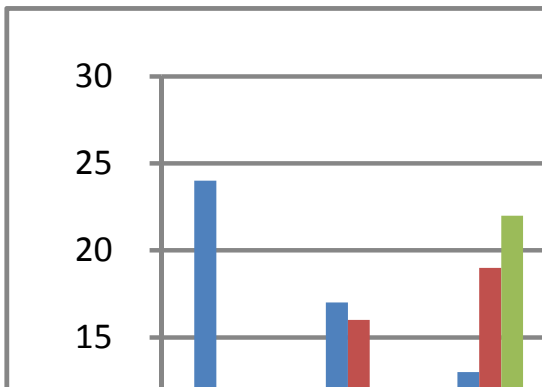


**Figure 4. Age Distribution of Rib Fractures in Frontal Crash Occupants age 20~79, NASS 1993-1996.**

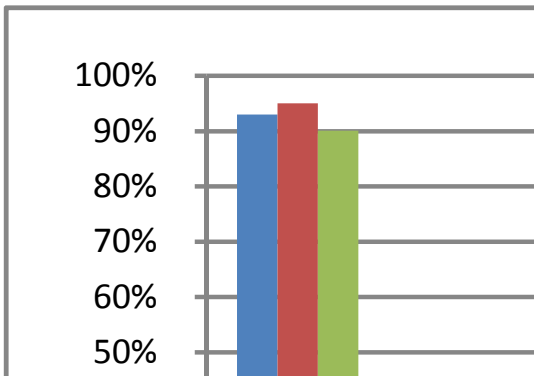


**Figure 5. Head and Chest MAIS by Driver Age Group - Frontal Impacts.**

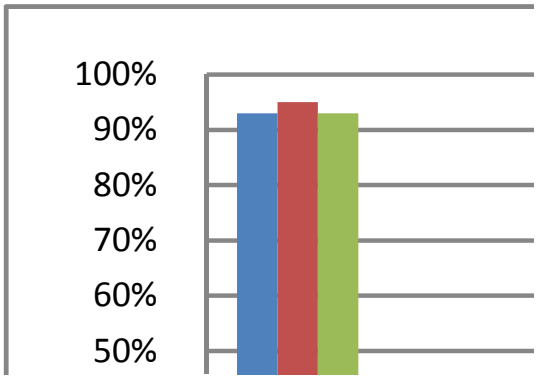


**Figure 6. Head and Chest MAIS by Passenger Age Group - Frontal Impacts.**

According to the R. Welsh paper, there is no significant difference in MAIS 2 or less head injury among the different age group selected frontal collision accident database of seatbelt restrained driver and passenger only. But, older age group was more experienced in sever thoracic injury.

**Korean Elderly Occupant Accident Characteristics**

7 years period of accident database (2000-2007) was statistically evaluated to examine the elderly occupant's accident patterns and injury types. The total 64,424 car-to-car type frontal accidents was scanned but injury involved 32,195 accidents (injured person: 61,645) was collected as 1st data set. After eliminate the improper data not provide sufficient information, the final data set was targeted 26,057 injured accidents. The data was categorized 4 different age group, such as less than 25 year old, 25 year to 54 year, 55 year to 64 year and 65 year and older. The injury characteristics were classified by 9 AIS injured body segment classes. The 3 highly injured body parts compared with other age groups were carefully investigated to find any statistical significant. From results, the elderly occupants exposed higher risk in thorax, head and abdomen. The thoracic injury risk is 2.6 time higher than other ages. The head injury is 1.3 time higher and abdomen injury is 1.9 time higher. The abdomen of male elderly injury is 26.2% higher than that of female elderly occupant. But, female elderly has higher potential risk in head and lower extremity 57% and 11.6% respectively more than those of male elderly.

In seating position, driver side is 2.9 time more suffered thorax injury compared with 25 - 54 year old age group. The elderly occupant seated in front passenger seat or rear seats reveals 1.4 - 1.8 times higher injuries in abdomen and lower extremity as well as thorax injury.

Regardless the type of vehicles, the thorax injury of the elderly occupant is more than 1.7 - 2.1 times more frequently occurred. The elderly seated in SUV and RV vehicles are more injured than sedan type vehicle during the car-to-car frontal collisions. The seat belted elderly is more suffered thorax, abdomen and upper extremity injuries than other age groups. However, compared with non belted occupants, there are no differences in terms of injury between different age groups. Even the airbag equipped vehicle cases, still elderly occupants exposed 12.9% more sever thorax injury compared with other age group.

**Table 1. Injury Patterns with Different Age Group in Car-to-Car Frontal Accidents**

| | MAIS 3↑ | | | | MAIS 2↓ | | | |
|---|---|---|---|---|---|---|---|---|
| Age | ~ 24 | 25 ~ 54 | 55 ~ 64 | 65 ~ | ~ 24 | 25 ~ 54 | 55 ~ 64 | 65 ~ |
| Head | 28 | 194 | 34 | 20 | 736 | 4,316 | 505 | 220 |
| Neck | 52 | 420 | 84 | 37 | 2,078 | 11,719 | 1,265 | 473 |
| Lumber | 19 | 219 | 47 | 27 | 179 | 1,142 | 136 | 55 |
| Thorax | 25 | 325 | 55 | 41 | 14 | 1,91 | 36 | 24 |
| Abdomen | 37 | 192 | 31 | 21 | 59 | 212 | 29 | 21 |
| Arm | 53 | 402 | 54 | 40 | 316 | 1,613 | 156 | 87 |
| Leg | 41 | 244 | 33 | 21 | 177 | 810 | 83 | 38 |
| Whole Body | 21 | 86 | 18 | 14 | 45 | 275 | 30 | 13 |
| Total | 227 | 1,408 | 246 | 153 | 3,508 | 19,314 | 2,248 | 987 |

## KOREAN ELDERLY HYBRID III TYPE DUMMY MODEL

### Dimension of Korean Elderly

In order to develop the elderly friendly vehicle and special injury criteria for elderly occupant, it is need to define the standard elderly person. In this study, 65 year and older male is defined as the elderly. The SizeKorea database was applied to develop the computer simulation model. The physical characteristics of elderly Korean occupant are relatively small and lighter than that of western elderly. Data from the SizeKorea database (total surveyed number of subjects in SizeKorea database was 14,200 between 0 to 90 years old), the 50th %tile height and weight of the subjects in target group (527 male samples) were 162.8cm and 62kg, respectively. Table 2 show the height, weight and seated height of 50%tile Korean elderly male standard.

**Table 2. Body Dimensions of Korea Elderly**

| | 50%tile | Mean |
|---|---|---|
| Weight (kg) | 62.1 | 62.34 |
| Height (mm) | 1627.5 | 1629.62 |
| Seated Height (mm) | 973.5 | 971.57 |

### Development of Korean Elderly Hybrid III Type Dummy

The MADYMO / Scaler has been created to scale occupant models in MADYMO (DE LANGE, 2005). It allows the user to scale a model in three different ways:

1) Specifying gender, mass and standing height for creating a model based on the GEBOD anthropomorphic database (BAUGHMAN, 1986)

2) Specifying a data set of 35 anthropomorphic values.

3) Specifying direct scaling factors $\lambda_x$, $\lambda_y$, $\lambda_z$ and $\lambda_{xyz}$ for each dimension of the 14 scalable body sections.

The definitions of the anthropomorphic values are given in the MADYMO Utilities Manual Release 6.3.1 (2006). With respect to the dimensions, x is always referring to the depth of a body section (e. g. “chest depth” for body region “thoracic spine”, y to its lateral width (e. g. “head breadth ”for region “head” and z to its height (e. g. “knee height seated” for region “lower leg”).

In this study, using SizeKorea database for 65 year and older person's body dimension, the second scaling method is taken to develop the Korean elderly Hybrid III 50% male dummy model. The 35 body dimension list is shown in Table 3. The dimensions of item 5, 14, 15 and 22 were not listed in the SizeKorea database. These dimension were generated using GEBOD program by input the weight and standing height. With given dimensional data, the Korean elderly size dummy is created as shown in Figure 7.

The results of the converted dimension for Korean elderly 50%tile is shown in Table 4 with high accuracy.

**Table 3. Anthropomorphic data set for scaling**

| No. | Items | Hybrid Ⅲ | Korean Elderly |
|---|---|---|---|
| 1 | Weight (kg) | 77.14 | 62.1 |
| 2 | Standing Height (mm) | 1,690 | 1,6275 |
| 3 | Shoulder Height (mm) | 1,396 | 1,328 |
| 4 | Armpit Height (mm) | 1,301 | 1,2105 |
| 5 | Waist Height (mm) | 1,007 | 962.9 |
| 6 | Seated Height (mm) | 902 | 873.5 |
| 7 | Head Length (mm) | 209 | 188 |

| | | | |
|---|---|---|---|
| 8 | Head Breadth (mm) | 146 | 146.5 |
| 9 | Head to Chin Height (mm) | 228 | 201.5 |
| 10 | Neck Circumference (mm) | 370 | 371.5 |
| 11 | Shoulder breadth (mm) | 437 | 369.5 |
| 12 | Chest Depth (mm) | 260 | 220.5 |
| 13 | Chest Breath (mm) | 316 | 294.5 |
| 14 | Waist Depth (mm) | 223 | 208 |
| 15 | Waist Breadth (mm) | 280 | 284.9 |
| 16 | Buttock Depth (mm) | 236 | 234.5 |
| 17 | Hip Breath, Standing (mm) | 366 | 321.5 |
| 18 | Shoulder to Elbow Length (mm) | 341 | 330.5 |
| 19 | Forearm-Hand Length (mm) | 460 | 440.5 |
| 20 | Biceps Circumference (mm) | 286 | 280.5 |
| 21 | Elbow Circumference (mm) | 286 | 271.5 |

| | | | |
|---|---|---|---|
| 22 | Knee Height, Seated (mm) | 563 | 489.5 |
| 23 | Forearm Circumference (mm) | 276 | 267 |
| 24 | Wrist Circumference (mm) | 174 | 168.5 |
| 25 | Thigh Circumference (mm) | 541 | 506.5 |
| 26 | Upper Leg Circumference (mm) | 534 | 465.5 |
| 27 | Knee Circumference (mm) | 416 | 356.5 |
| 28 | Calf Circumference (mm) | 358 | 339.5 |
| 29 | Ankle Circumference (mm) | 223 | 250.5 |
| 30 | Ankle Height, Outside (mm) | 120 | 67.5 |
| 31 | Foot Breath (mm) | 92 | 99.7 |
| 32 | Foot Length (mm) | 267 | 246.5 |
| 33 | Hand Breadth (mm) | 96 | 82.5 |
| 34 | Hand Length (mm) | 168 | 182.5 |
| 35 | Hand Depth (mm) | 50 | 26.5 |

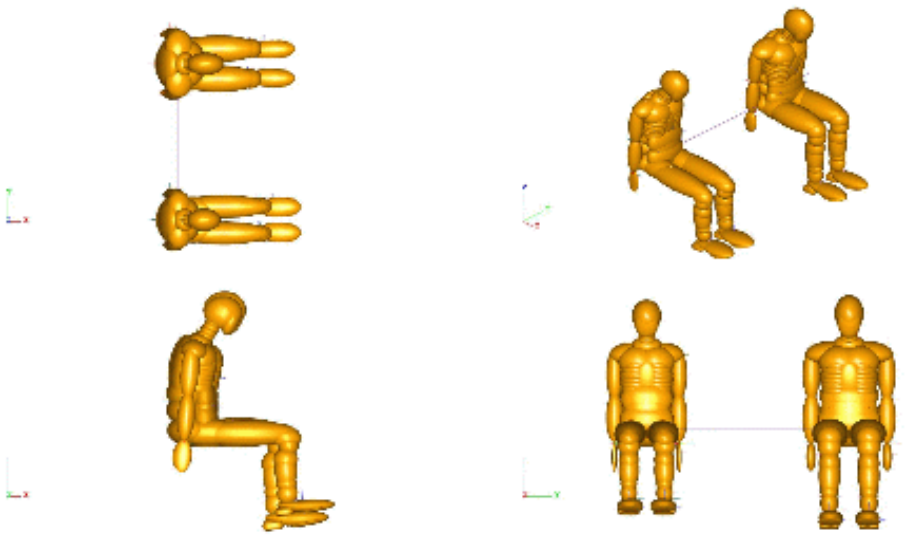

**Figure 7. Comparison of the Original Hybrid Ⅲ 50%ile Dummy(right) and the Scaled Hybrid Ⅲ Korea Elderly Dummy(left).**

**Table 4 Results of Model Scaling**

| Parameters | Requested | Modeled | Ratio (%) |
|---|---|---|---|
| **Weight** | 62.1 | 62.1199 | 100.03 |
| **Standing Height** | 1.6275 | 1.6279 | 100.02 |
| **Seated Height** | 0.8735 | 0.8734 | 99.99 |
| **Shoulder Breadth** | 0.3695 | 0.3696 | 100.03 |

**Computer Simulation Analysis**

**Occupant Simulation Model** - The converted Korean Elderly 50%tile Hybrid III Dummy model has been constructed with sled test model to compare with 50%tile standard Hybrid III model. In the simulation, occupant kinematics and injury values are examined to find relationship between two dummy models. From the accident data analysis and literature survey, since the most sever injury for the elderly occupant is thoracic injury, the detailed seat belt and airbag model are added in the typical sled model. In the seat belt model, load-limiter and pre-tensioner are also adopted as shown in Figure 8.

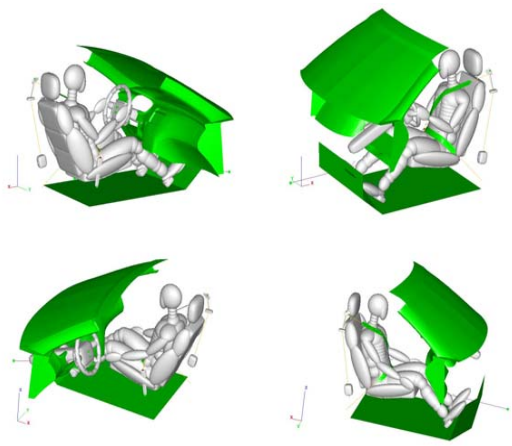

**Figure 8. Configurations of the Frontal Sled Simulation model with A/bag and Seat Belt**

**Simulation Results** - In the simulation, the various force level of load-limiters were examined to define the influence of belt force level. Table 6 shows the simulation results of driver side and Table 7 is results of passenger side. The current 2+1kN dual stage load-limiter is optimized to protect Hybrid III 50%tile male dummy both in driver and passenger side. The lower force load-limiter can help to reduce chest deflection in standard 50%tile Hybrid III, but the other injuries were getting worse.

In other hand, since the load-limiter and pre-tensioner is not intended to design for elderly occupant, there are rooms for improvements.

**Table 6 Results of Elderly Driver Dummy Model**

| Driver | Original Dummy (50%ile) | | | Scaling of Dummy (Only size) | | |
|---|---|---|---|---|---|---|
| Load-limiter (DLL) kN | 1.5+1 | 2+1 | 3+1 | 1.5+1 | 2+1 | 3+1 |
| Head (HIC36) | 380.31 | 357.65 | 396.09 | 371.28 | 385.44 | 467.5 |
| Chest def. (mm) | 33.37 | 35.74 | 40.7 | 26.4 | 30.44 | 35.02 |
| Chest acc (g) | 47.11 | 46.14 | 49.38 | 46.82 | 45.06 | 49.51 |
| Femur (kN) | 5.50 | 5.3 | 5.21 | 9.95 | 8.87 | 9.33 |

**Table 7 Results of Elderly Passenger Dummy Model**

| Passenger | Original Dummy (50%ile) | | | Scaling of Dummy (Only size) | | |
|---|---|---|---|---|---|---|
| Load-limiter (SLL) kN | 1.5 | 2 | 3 | 1.5 | 2 | 3 |
| Head (HIC36) | 361.44 | 323.87 | 301.25 | 321.87 | 286.17 | 305.05 |
| Chest def. (mm) | 31.67 | 26.88 | 30.54 | 18.02 | 21.11 | 26.15 |
| Chest acc (g) | 45.59 | 42.08 | 43.29 | 37.51 | 38.45 | 45.08 |
| Femur (kN) | 8.30 | 8.17 | 9.19 | 9.71 | 9.61 | 9.68 |

As given same crash severity, the Korean elderly model is less weight and height. Due to the small moment of inertia during the ride-down stage, the force acting on the head and trunk is less than standard size Hybrid III dummy. Therefore, except femur load, the injury, HIC, Chest deflection, Chest acceleration is less than standard size Hybrid III dummy.

It is also well established that the human injury tolerance decreases as the age increases. An aging

person becomes increasingly susceptible to sustain thoracic injuries, primarily rib fractures, during a car crash. In the development of the human injury tolerance criteria for automotive crashes, only a few researchers have paid attention to age effects. About age-related changes occurred in the thorax, the degeneration of human bones and soft tissues is an important factor which modified significantly their mechanical properties. The material properties of the bone obviously have a significant influence on the condition at which fractures occur. In general, all humans begin to lose progressively bone mass at the age between 30 and 40 as a result of a physiologic inability to maintain a positive balance between the removal of old bone and the replacement of new bone. After 55 years old, the decrease in bone mineral content becomes more pronounced, and the negative skeletal balance increases significantly between ages of 60 to 70. The chest deflection injury threshold is strongly dependent upon the age of the subject as shown in Figure 9. From R. Kent's curve, the chest deflection of standard size Hybrid III dummy is 35.74 mm with 260 mm chest circumference and the percentage of deflection rate is about 13.74. Korean elderly occupant has been experienced 30.44 mm chest deflection who has 220.5 mm chest circumference size. Although the chest deflection was less than the standard Hybrid III, the chest deflection rate is about equal. From Figure 9, 13.8 % of chest deflection rate is 5% of probability which 0+ number of rib fractures injury for the 30 year old adult. But 13.8% of chest deflection rate for the elderly occupant may occur 50% of .0+ number of rib fractures injury probability. The same rate chest deflection, but the different level of injury can be expected.

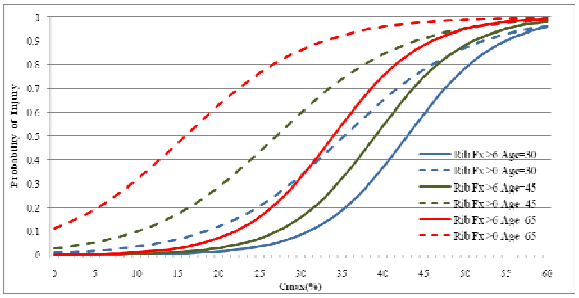


**Figure 9. Thoracic Injury Probability Curves in Deflection Rate of Rib Based on Kent (7).**

## CONCLUSIONS

Analysis of traffic accident data, the fatality and injury of elderly occupants are continuously increasing. As entering the aging society, safety issues for elderly driver and passenger must be carefully studied to provide the best possible protections or special safety regulation for elderly occupants. To provide optimal restraint system for the elderly, the scaled Korean elderly occupant dummy model was developed. With this model, the sled type simulation was conducted to examine the elderly injury and to find the suitable converting table for injury criteria for the safety standard.

## ACKNOWLEDGEMENTS

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