ANALYSIS OF ABDOMINAL INJURIES IN OBESE AND NONOBESE RESTRAINED OCCUPANTS

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ABSTRACT

This study clarified the effect of body physique to abdominal injury distribution in terms of frontal passengers at frontal collision using NASS/CDS database with medical knowledge and engineering analysis.

Present research based on the real-world accident data showed that distribution and severity of abdominal injuries of the restrained front seat occupants in frontal collisions was reflected by the body physique. Obese occupants tend to suffer from the injuries of middle-lower abdomen owing to the seatbelt compression. From the reconstruction of the occupants' kinematics, severity of abdominal injuries largely depended on the pelvic displacement in both obese and nonobese occupants. Therefore, to decrease the severity of abdominal injuries, knee airbag is one of considered proper devices as restraint systems for controlling pelvic displacement.

The result of frontal collision simulation with human model THUMS with various body physiques clearly shows that the mechanism and the effects of reduction of abdominal injuries.

INTRODUCTION

The restrained front seat passengers sometimes suffer from abdominal injuries in frontal collisions. However, there have been a few studies dealing with the abdominal injuries by seatbelt [1-3]. Furthermore, obesity has become a serious worldwide problem involving 500 million persons. Owing to the protrusion of the abdomen, obese occupants considered as more suffer from severe abdominal injuries in frontal collisions.

To clarify the difference of pattern and severity of abdominal injuries between obese and nonobese occupants, retrospective analysis using real-world accident data was performed. Then, the kinematics of occupants of the obese and nonobese occupants was reconstructed with finite element model.

METHOD

National Automotive Sampling System /Crashworthiness Data System (NASS/CDS) database was used to investigate the abdominal injuries of the front passengers in frontal collisions. In the analysis, 5280 front passengers in passenger vehicles and commercial vehicles were extracted from 1995 to 2011.

Note that the dataset of NASS/CDS has about ten thousand in traffic accident deaths and injuries every year, and which occupies about 0.3% of 3.2 million people in 1999[4].

In this study, frontal collision is defined from eleven o'clock to one o'clock in impact direction, front side of vehicle was damaged. To evaluate the trend in adult, the occupants with height of more than 140cm was examined.

Furthermore, to understand the mechanism of abdominal injuries of restrained front passengers, kinematics of the occupants at the collision was

reconstructed using the modified THUMS, version 3.

ANALYSIS OF ABDOMINAL INJURY IN FRONTAL COLLISION

Injury Part and Injury Severity

To clarify abdominal injuries ratio of total injuries in frontal collision, injuries of 5280 front passengers were analyzed with injury body regions and injury severity (AIS). To conduct accurate analysis, 4365 injuries with AIS of 2 or more were selected.

First, distributions of injuries by the region and severity are shown in Figure1. The abdomen (401) is less common than the lower limb (889), head (804), chest (783) and upper limb (658). However, severe injuries, AIS of 4 or more, are occurred at only three body regions: the head, chest and abdomen. In these injuries, injuried body regions which led to death were the chest (92), head (91), abdomen (24). Therefore, to lessen the fatalities, abdominal injuries in frontal collision should also be prevented.

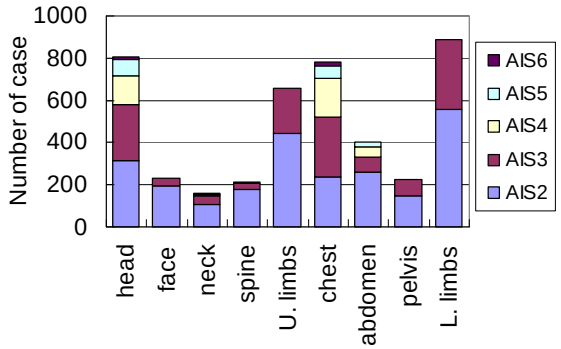

Figure 1. Distribution of injuries by AIS.

Abdominal Injury and Effect of Restraint System

To clarify the effects of occupant restraint system, injuries of front passengers in frontal collision with seatbelt or without seatbelt were analyzed. Number of unbelted occupants was 1185, belted occupants was 3596, and unknown was 499 among 5280 front passengers.

To determine the injury frequency for each body region, the number of injury occurrence of AIS of 2 or more for each body region was divided by the number of belted or unbelted occupants, respectively. The effectiveness of seatbelt was confirmed: AIS of 2 or more injury was smaller for belted occupants than the unbelted occupants for all body regions. Especially reduction rate of the head was 79%, face was 84%, neck was 71%, pelvis was 76%, and lower limbs were 65 %. Significant effect of wearing seatbelt was observed in the head, neck part and lower body (Figure 2). On the other hand, the reduction rate of abdominal injuries with belt restraint in the abdomen is 53%, smaller value than as shown in the head or neck.

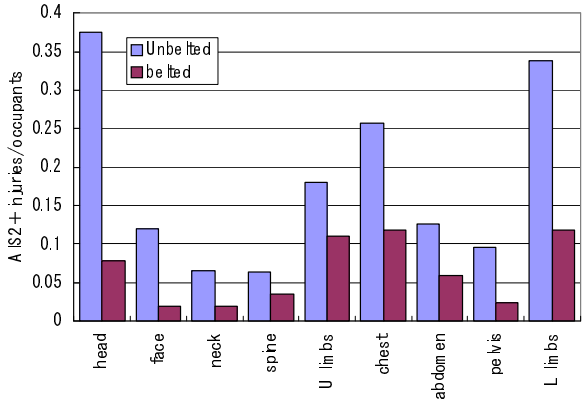

Figure 2. Incidence of AIS 2+ injuries by seatbelt.

This trend is more noticeable for the persons with AIS of 3 or more. Injury reduction rate by seatbelt was at the head 81%, face 86%, neck 83%, pelvis 81%, lower limbs 73%, however, the value is smaller, 43%, at the abdomen. The seatbelt effectiveness for preventing abdomen injuries was limited (Figure 3). These results suggest that the prevention of the abdominal injury by seatbelt or airbag in frontal collisions is more difficult than that of other body regions.

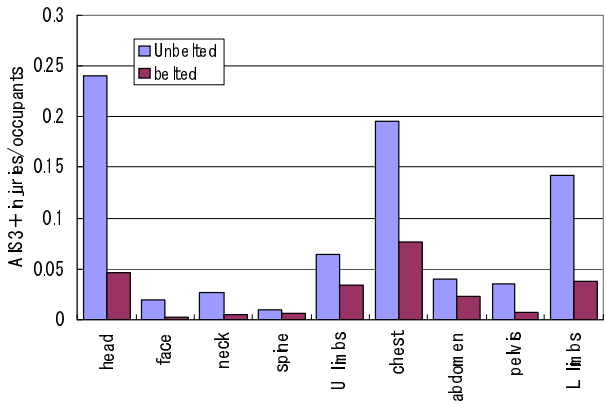

Figure 3. Incidence of AIS 3+ injuries by seatbelt.

For the front seat occupants at frontal collisions, we

divided them for three groups: the cause of death was due to the head injuries (head group), chest injuries (chest group) or abdominal injuries (abdomen group).

Then, distribution of the survival time in each group was examined. The rates of the persons died within one hour of the collision were 37% in the head and 40% in the chest group, however, smaller as 24% in the abdomen group (Figures 4 – 6).

When comparing the AIS in each group, mean abdomen AIS in abdomen group (3.8) was smaller than mean chest AIS in chest group (4.4) or mean head AIS in head group (4.3).

If adequately treated, fatality may be more reduced for the abdominal injuries than the head or chest injuries. Consequently, clarifying the abdominal injury site and its causing mechanism is important in order to reduce the number of fatal and serious injuries in frontal collisions.

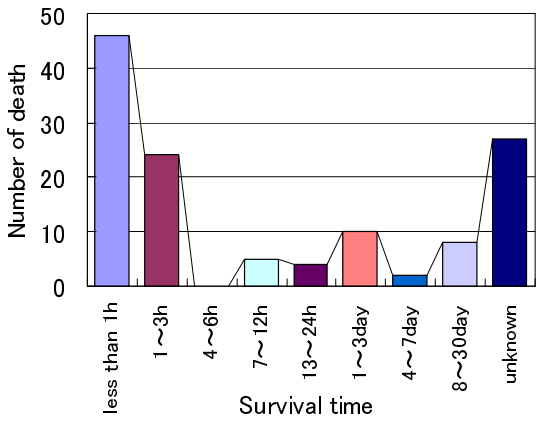

Figure 4. Distribution of survival time (head group).

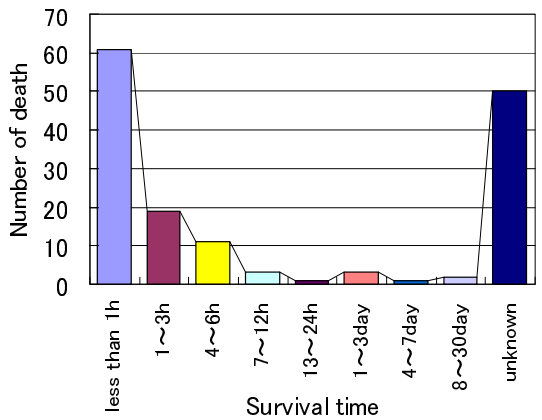

Figure 5. Distribution of survival time (chest group).

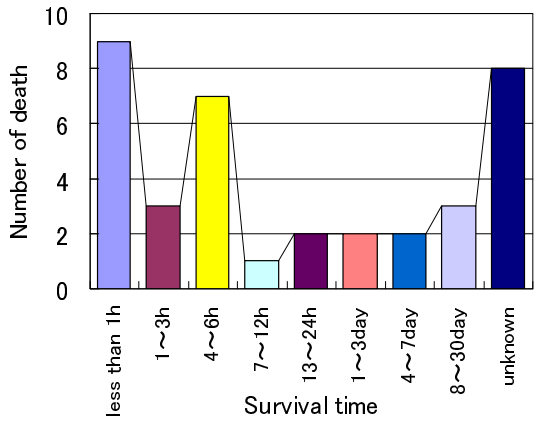

Figure 6. Distribution of survival time (abdomen group).

Abdominal Injury Factor of Occupant with Seatbelt

Concerning the injury source of 213 abdominal injuries with seatbelt, the compression by seatbelt accounts for more than 60% (Figure 7).

As other sources of injury than seatbelt, there are cases of door trim or center console, which suggests that the front passenger was thrown out in an oblique or side direction. However, in order to analyze mechanisms of injuries in frontal collisions, we focused on the seatbelt injuries which accounts for more than 60%.

The 131 abdominal injuries caused by lap belt were classified by injured organs as follows: the liver 29 (21%); spleen 40 (29%); intestine (small intestine, large intestine and mesenterium) 43 (31%). Accordingly, the three organs of liver, spleen and intestine accounted for 82% (Figure 8).

The abdominal injuries due to lap belt also involved kidneys (8%) and diaphragma (6%). Because kidneys are located in the retroperitoneum and diaphragma could be damaged by chest compression, these injuries were excluded for analysis. Finally, the liver, spleen, intestine by lap belt were examined.

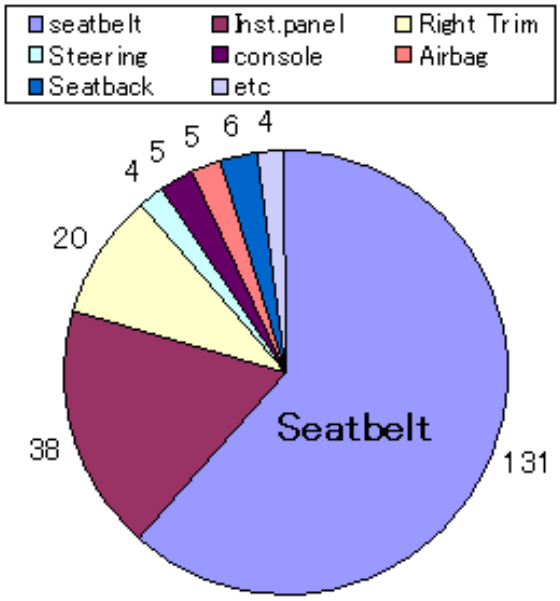

Figure 7. The source of abdominal injuries with AIS 2+ caused by seatbelt.

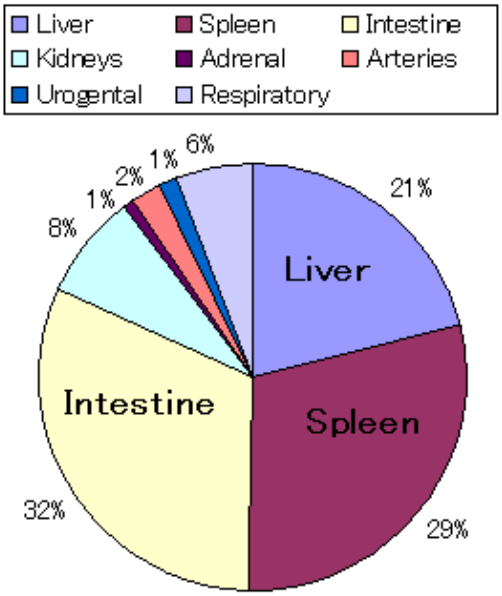

Figure 8. Distribution of involved organs in the abdominal injuries with AIS 2+ caused by seatbelt.

Body Physique and Abdominal Injury with Seatbelt

To clarify the relationship between obesity and abdominal injuries, 112 cases (except one case of unknown body weight) of abdominal injuries by lap belt were analyzed. Body mass index (BMI) was calculated with body weight divided by square of height. For the 111 cases, occupants were divided as obese (BMI ≥ 25, 51 cases) or nonobese (BMI < 25, 60 cases).

Table 1.
Abdominal injuries with AIS2+ caused by seatbelt

	BMI＜25	BMI≧25
Liver	20 (33%)	9 (18%)
Spleen	26 (44%)	13 (25%)
Intestine	14 (23%)	29 (57%)
Total	60	50
Ave,height(cm)	164.5	162.0
Ave,weight(kg)	57.6	80.2
Ave.EBS (kph)	45.1	51.5
Ave.BMI	21.3	30.6

Distributions of injured region, background of the occupants in both obese and nonobese groups are shown in Table 1.

In the view point of position of the organs, the liver and spleen is located in the upper abdomen, and the intestine is located mainly in the middle-lower abdomen (Figure 9).

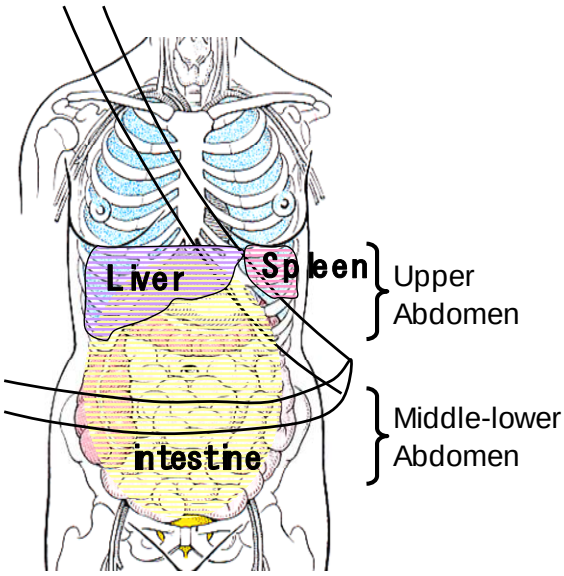

Figure 9. Abdominal organs [5].

Then, we further divided the occupants with injuries in the upper abdomen or in the middle-lower abdomen. Most of obese occupants suffer from

middle-lower abdominal injuries (57%), whereas, nonobese mostly (77%) suffer from upper abdominal injuries (Figures 10 and 11).

The differences of proportion were statistically significant (Chi-square test, $P < 0.0003$).

Owing to the protrusion of the middle-lower abdomen with obesity, the distribution of abdominal injuries was changed.

For the obese occupants, as seatbelt is easily penetrate into the abdomen, it is desirable to put the lap belt on the lower abdominal iliac in obese occupants.

Although, the number of injuries of the upper abdomen was decreased in obese occupants deteriorated rather in the mean AIS. Especially for the spleen, the mean AIS was 2.85.

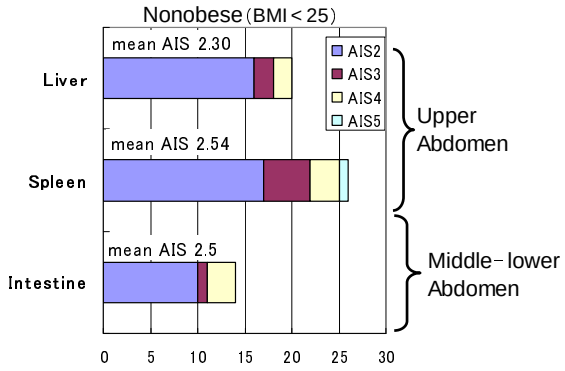

Figure 10. Distribution of injured organ and the mean AIS for the abdominal injuries with AIS 2+ (nonobese restrained occupants).

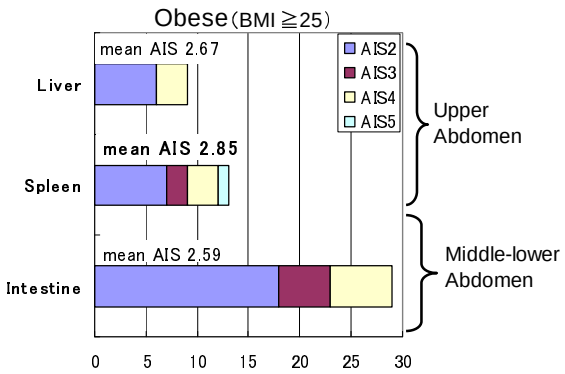

Figure 11. Distribution of injured organ and the mean AIS for the abdominal injuries with AIS 2+ (obese restrained occupants).

VERIFICATION USING HUMAN MODEL

To verify the trend of the abdominal injuries of obese occupants, obese human finite element (FE) model was made based on THUMS, version 3. The base THUMS was AM50th percentile of 175 cm height and 78 kg weight (equivalent of BMI 25). In addition to the AM50th occupant, the FE simulation of obese occupant was carried out. As reference data, the obese occupant with 168 cm height and 111 kg weight was quoted from CIREN presentations [6]. Based on the thickness of subcutaneous fat shown in abdominal CT image, body surface of original THUMS was scaled up to BMI of 34 with 105 kg weight using weight ratio in Table 2. FE simulation represented a sled test of frontal collision at impact velocity of 56 km/h (35 mph) because the average EBS (Equivalent Barrier Speed) exceeded 50 km/h in abdominal injuries of obese occupants in accident data. The simulation was conducted for AM50th and obese occupants seated in the front passenger with restraint system of airbag and seatbelt to evaluate the injury risk of abdomen for the normal lap belt position (Figures 12 and 13).

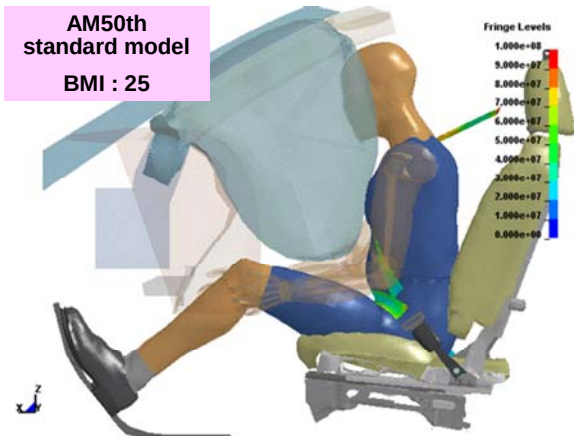

Figure 12. 35 mph sled FE simulation (AM50th standard model: BMI 25).

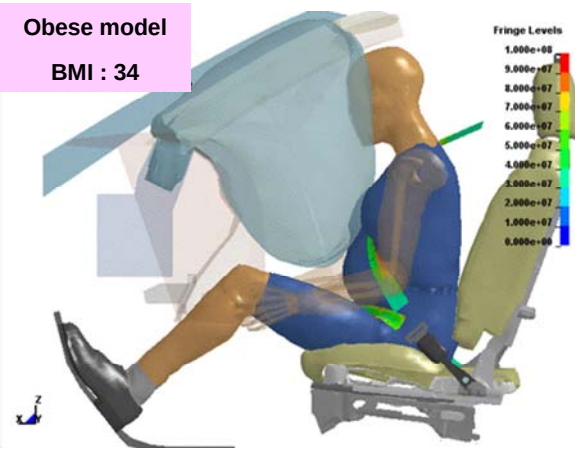

Figure 13. 35 mph sled FE simulation (obese model: BMI 34).

Table 2 presents the ratio of the obese model to AM50th standard model for the body weight and seatbelt contact force. The body weight ratio was 1.35. For the contact force between the shoulder belt and the upper abdomen, the ratio of the obese model to AM50th was 1.19. For the contact force between the lap belt and the middle-lower abdomen, this ratio was 1.42. Therefore, the load to the abdomen caused by the lap belt was larger in obese occupants. This result was coinciding with the accident data that the intestine injuries were observed frequently to the obese occupants (Figure 11).

Table 2.
The ratio of the obese model to AM50th standard model

	Standard (BMI 25)	Obese (BMI 34)
Weight (kg)	78	105
Weight ratio	1.00	1.35
Shoulder belt force ratio	1.00	1.19
Lap belt force ratio	1.00	1.42

Figures 14 and 15 show the stress of the seatbelt for the AM50th standard model and obese model. The shoulder belt path of the obese occupant model can shift in the lateral direction from the medium location because of the protruding abdomen. As a result, the shifted shoulder belt can compress the spleen. This can be a reason why the AIS of the spleen injuries were larger for the obese occupants.

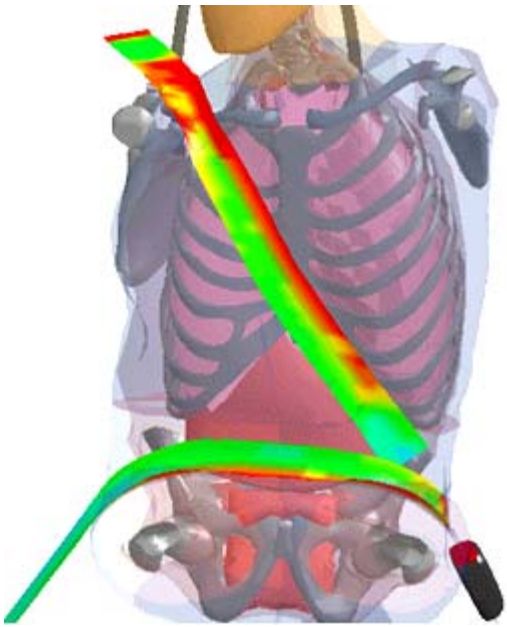

Figure 14. Seatbelt stress at sled FE simulation (AM50th standard model: BMI 25).

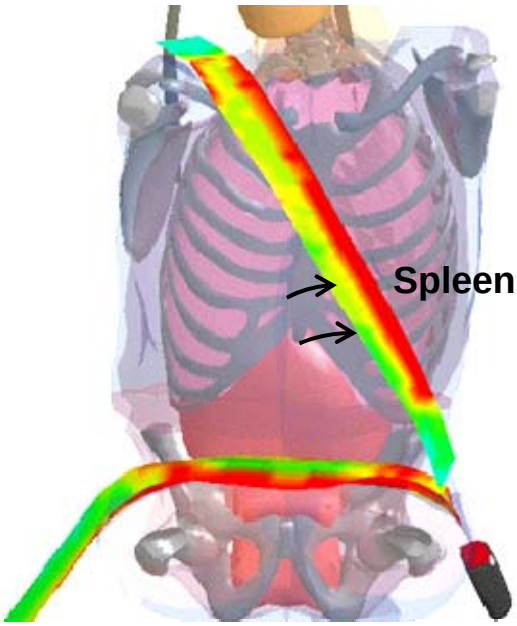

Figure 15. Seatbelt stress at sled FE simulation (obese model: BMI 34).

It is known that the knee airbag (KAB) can reduce the lap belt force in addition that it can reduce the knee injury risks. In this study, the possibility of knee airbag to reduce the abdominal injury risks of obese occupants by the reduction of the lap belt contact force, was examined. Figure 16 and 17 show the shoulder belt and lap belt force for the AM50th

occupant and obese occupant, respectively. There was no significant change in the shoulder belt contact force by equipping the knee airbag. However, lap belt contact force of the obese model can be reduced significantly, and its level was comparable with the AM50th standard model. It was shown that the knee airbag could be effective to reduce the injury risk of the lower abdomen.

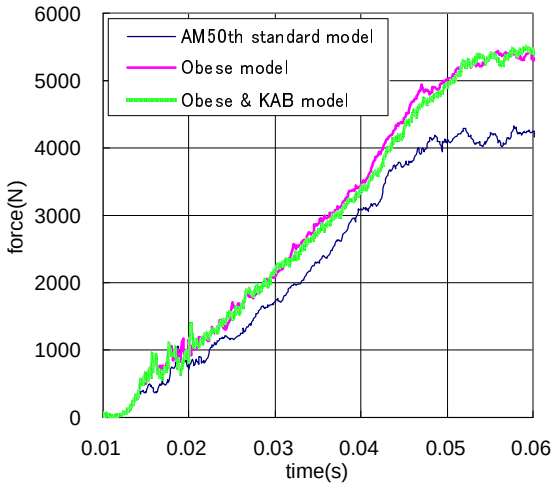

Figure 16. Shoulder belt contact forces.

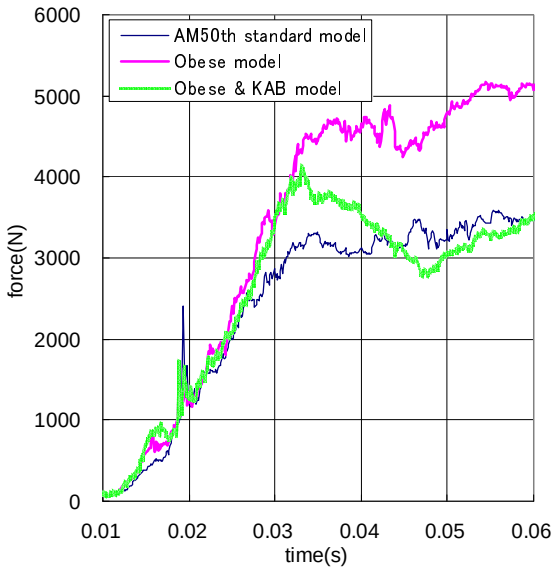

Figure 17. Lap belt contact forces.

CONCLUSIONS

Injuries of front passengers in frontal collisions were analyzed using NASS/CDS database. The following results were obtained with medical and engineering viewpoints:

1. Abdominal injuries are the third part of severe injury following the head and chest. More than 60% of abdominal injuries of restrained front seat occupants are caused by seatbelt. Among them, the liver, spleen and intestine accounted 82% of visceral injuries of the abdomen by seatbelt.
2. Abdominal injuries by lap belt depend heavily on body physique. Nonobese occupants more suffer from injuries at the upper abdomen and obese more suffer from middle-lower abdomen.
3. Obese human FE model (BMI 34) was developed for sled simulation at 56 km/h. The contact force of lap belt with the middle-lower abdomen was significant larger in obese occupants.
4. According to the FE simulation, it was shown that the knee airbag was effective to reduce lap belt contact force with middle-lower abdomen of obese FE model. The knee airbag has a potential to reduce abdominal injuries to the obese occupants.

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