AN EXPERIMENTAL ANALYSIS OF THE ABDOMINAL PRESSURE OF THE PREGNANT OCCUPANTS DURING AUTOMOTIVE COLLISION USING AF5 PREGNANT DUMMY

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ABSTRACT

Previously the correlation between the fetal outcome and the injury severity of the pregnant women in automotive collisions were addressed by the authors using the data of the insurance refunds in Japan. The study showed that injury severity scores did not differ significantly between the pregnant occupants with spontaneous abortion and with healthy newborn although the scores were significantly higher in the pregnant occupants whose neonate died. The authors have indicated the prediction of negative fetal outcome with anatomical injury severity of the mothers. Therefore in this study, the abdominal pressure of the pregnant occupant during collisions was focused as a possible predictor of fetal outcome. A series of sled experiment was conducted using the pregnant dummy which represents the anthropometry of the pregnant woman with the gestational age of 30 weeks. The MAMA-2B （Maternal Anthropometric Measurement Apparatus, version 2B） pregnant dummy based on the Hybrid-3 AF5th percentile dummy developed by First Technology Safety Systems Inc. and UMTRI (University of Michigan Transportation Research Institute) was used for the experiments. The values of the pressure during rear impact in a passenger vehicle were measured and compared. The seating posture of the dummy in the experiments was determined by the measurement of pregnant volunteers in an actual passenger vehicle. From the results of the experiments the dominant factor of the change of the abdominal pressure was discussed.

INTRODUCTION

According to Connolly et al., 6–7% of pregnant women suffer some kind of traumatic injuries during pregnancy; approximately two-thirds of such injuries reportedly occur during traffic accidents.(1) Klinich et al., also suggested that 1.3 million women in later terms of pregnancy are involved in traffic accidents in the United States every year, and an estimated 1,500–5,000 abortions or stillbirths occur annually.(2) To reduce traffic accident fatalities, fetal safety might become one of an important issue in the future.

The authors have already examined the relationship between traffic injuries to pregnant women and the associated fetal outcomes. (3-4) In those reports the circumstances of accidents and the injuries to mothers and fetuses in cases in which claims for payment were made under automobile insurance policies were analyzed. The number of insurance claims made was broken down by what the pregnant women were doing when they were injured, and the results show that the largest number, at 46%, were driving automobiles. However, from the study the difficulty was indicated in the prediction of negative fetal outcome with anatomical injury severity of the mothers. Injury severity scores did not differ significantly between the pregnant occupants with spontaneous abortion and with healthy newborn although the scores were significantly higher in the pregnant occupants whose neonate died. Therefore, clarification of the actual circumstances under which pregnant female drivers are involved in accidents, together with the injury mechanisms during slight impacts as well as high-energy impacts, are needed.

In this study, to investigate the correlation between the injury mechanisms of pregnant female drivers and the associated fetal outcomes, a series of rear impact sled tests were conducted by using a pregnant dummy.

METHOD

The authors of this research contend there is a strong likelihood that fetal death or abortion takes place when pregnant women are involved in traffic accidents in which external force is applied to their abdomens. (3-4)However, so far as it is known, the injury mechanisms for pregnant women and fetuses in traffic accidents have not yet been completely explained.

Needless to say, the greatest difference between pregnant women and non-pregnant women in terms of anthropometry is the forward protrusion of the abdomen. In collisions, there is forward displacement of the abdomen, resulting in likelihood of contact with interior parts of the automobile. Therefore, ascertaining the driving posture adopted by pregnant women, as well as the differences in their physiques, would be useful in determining the injury mechanisms. Duma et al. assessed pregnant passengers using finite element model simulation to estimate the stress exerted on their abdomens. (4) This study focused on the severe injuries due to frontal collisions with relatively high energy. However, the seating posture applied in the study was based on the measurements in the interior buck of University of Michigan Transportation Research Institute (UMTRI), would be somewhat different from those of actual vehicle. Further more, the authors have been unable to uncover any studies addressing the measurement of the responses of pregnant drivers during slight rear impacts.

Therefore in this study, to investigate the injury mechanisms of pregnant female drivers during rear impacts, a series of rear impact sled tests were conducted by using a pregnant dummy. The responses of impacts and kinematics of the dummy were examined. The seating posture of the dummy in the experiments was determined by the measurement of pregnant volunteers in an actual passenger vehicle. An actual automobile was used to determine the seat adjustment positions used by pregnant female drivers.

Measurement of seating posture

To determine the seat adjustment positions used by pregnant female drivers, the measurement of pregnant volunteers is conducted using an actual passenger vehicle. The gestational age of the pregnant drivers studied in the present research was set at about 30 weeks. An open call for volunteers was issued, and 20 pregnant women who drive a car regularly, were chosen as subjects for the research. The subjects who participated in this research were given full verbal and written explanations of the purpose and method of measurement in advance by a physician, after which the subjects signed their consent in writing. A typical mid-size passenger sedan was used for measurements. The subjects sat in the driver's seat. After receiving an explanation on how to adjust the seat, the subjects themselves adjusted the seat so that the seating posture was close to their normal ones as much as possible. Then the measurements were taken. The results were following.

Basic information: The mean age of the subjects was 30.0±3.0 years, with height of 160.8±6.6 cm, weight of 60.2±6.0 kg, gestational age of 31.4±1.9 weeks, and an abdominal circumference of 87.1±4.5 cm.

Seat adjustment position: The seat slide position was adjusted to 103±49 mm from the full-forward position, with the reclining angle of 7.1±3.0° from the full-forward position.

Position relative to the steering wheel: The horizontal distance from the lower rim of the steering wheel to the abdomen was 146±56 mm.

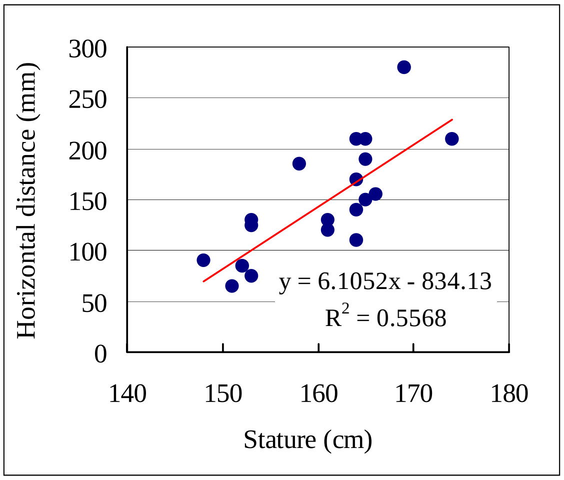


Figure 1. Horizontal distance between the lower rim of the steering wheel and the abdomen as a function of stature

Figure 1 shows the relationship between the horizontal distance from the lower rim of the steering wheel to the abdomen and the height of the subjects. This shows a somewhat strong correlation with the coefficient of 0.72.

Seating posture: The position of the head, the shoulders, and the pelvis were measured relative to the vehicle's reference points. The measurement points on the head, the shoulder and the pelvis were the center of the external acoustic opening, the center of the shoulder joint (the mid-point of the greater and lesser tubercles of the humerus) and the head of the femur, respectively.

Figure 2 shows a graph that represents the positions of the head, pelvis and shoulders of subjects using the horizontal(X) and vertical (Z) coordinates. The shape of the plotted lines in the graph represents a simplified form of the posture of the upper torso for each subject.

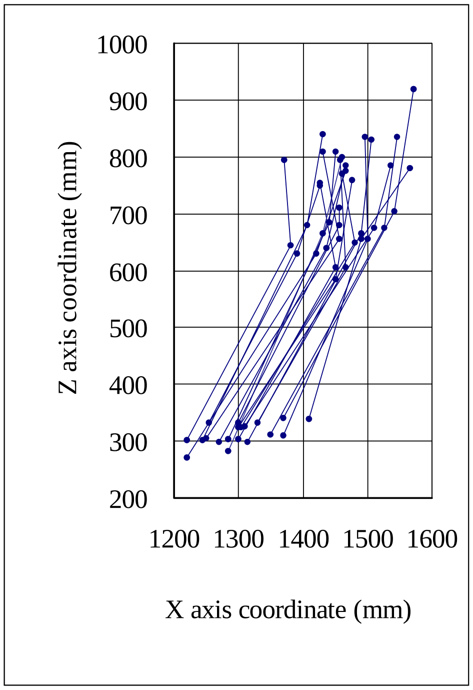


Figure 2. Seating postures represented by the hip, shoulder and head coordinates

Determination of the seating posture of the dummy

From the results of the measurement which shows somewhat strong correlation between the horizontal distance from the lower rim of the steering wheel to the abdomen and the height of the subjects, a verification of the second impact of the pregnant driver using AF5th percentile dummy was deemed appropriate. To determine the seating posture of the dummy from the results, the mean values of the measurements of seven chosen subjects whose anthropometric values are similar to that of AF5th percentile were obtained. The mean age of the chosen subjects was 28.7±2.4 years, with height of 152.6±3.0 cm, weight of 54.7±2.8 kg, gestational age of 30.8±1.0 weeks, and an abdominal circumference of 86.4±4.2 cm. The mean seat slide position was 65±30 mm from the full-forward position, with the reclining angle 7.4±3.0° from the full-forward position (torso angle of 13°). The horizontal distance from the lower rim of the steering wheel to the abdomen was 107±4.2mm. From the mean values of the chosen subjects, the seating posture of the dummy was determined as the seat slide position of 70mm from the full-forward position with the reclining angle of 8°, taking minimal pitch of seat adjusters into account.

Dummy

The dummy which was used in these experiments is the Maternal Anthropometric Measurement Apparatus, version 2B (MAMA-2B) pregnant dummy developed by First Technology Safety Systems and UMTRI in 2001. Although this is only one pregnant dummy commercially available, development is still on-going at right moment. The latest version which is called as the enhanced MAMA-2B, equipped with a pair of infra-red type chest deflection measurement devices, was used in this study. The history of the development of this dummy was already described in the literatures of Rupp et al. (6) and Ziao. (7) This dummy was developed based on the Hybrid-3 AF5th percentile dummy, by modifying the pelvis and the ribcage, to enable to install the bladder made of silicone rubber representing the uterus of 30 weeks of gestation. The bladder is approximately spherical in shape, approximately 200mm in diameter. Two pressure sensors are installed in the anterior and posterior surfaces of the inside of the bladder respectively. The bladder is filled with the water of 3000ml in use.

Sled pulse

To represent the status in which a pregnant driver encounters slight rear impact in a passenger vehicle, the sled pulse applied in the experiments was the trapezoid waveform, with the delta V of 24kph (mean acceleration of 6.5G), which is defined by the test protocol of Folksam, a representative third party assessment on the rear impacts injuries.

Test setup

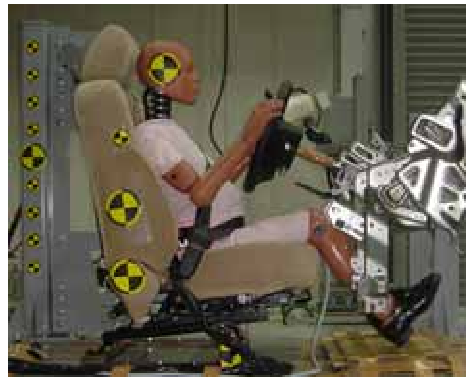
Figure 3 shows test setup. The Instron servo sled apparatus was used in the experiments. The seat, the seatbelt, the steering wheel, and the steering column installed in the setup were the same components and in the same relative position as the vehicle used in the measurements of the seating posture. Experiments with seatbelt and without seatbelt were both conducted and compared. The airbag and the pre-tensioner were not activated in all experiments.

Figure3. Sled setup for the experiments

Test matrix

First of all, experiments applying the dummy setting based on the FMVSS frontal impact test protocol were conducted, to compare the kinematics to that of the dummy setting based on the measurement of volunteers. According to the FMVSS protocol for the Hybrid-3 AF5th percentile dummy, seat slide position was determined from the full-forward position or the position at which the lower extremities of the dummy are closest to the dashboard of the testing vehicle unless they do not contact to it. In case of the vehicle used in the volunteer measurements, the position determined by this method is the full-forward position. However, the MAMA-2B could not sit this position due to interference of the abdominal protrusion with the lower rim of the steering wheel. Therefore, the position behind 30 mm from the full-forward position was determined as the dummy setting based on the FMVSS protocol concept (hereafter the MVSS setting).

As noted previously, the dummy setting based on the measurements of volunteers (hereafter the volunteers setting) was determined as the seat slide position of 70mm from the full-forward position with the reclining angle of 8°. The referential horizontal distance from the lower rim of the steering wheel to the abdomen was determined as 100mm. Figure 4 shows both settings. Table 1 shows the matrix of the status of the seatbelt and the dummy settings in the experiments.



MVSS setting

Volunteer setting

Figure 4. Dummy settings

Table 1. Matrix of the experiments

	Dummy setting	Seatbelt setting
Experiment 1	MVSS	Wear
Experiment 2	MVSS	Unwear
Experiment 3	Volunteers	Wear
Experiment 4	Volunteers	Unwear

RESULTS

Figure 5 shows the time histories of the acceleration applied to the sled setup. Figure 6 and 7 shows the time histories of the acceleration of the pelvis of the dummy. Figure 8 shows the time histories of the displacement of the pelvis and the chest of the dummy relative to the sled setup in the horizontal(X) axis. Figure 9 shows the time histories of the pressure of the abdominal bladder of the dummy.

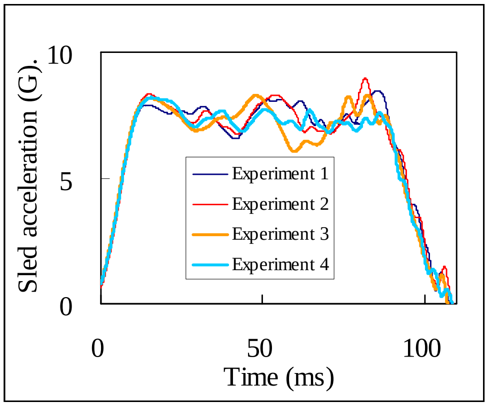


Figure 5. Time histories of the acceleration applied to the sled setup

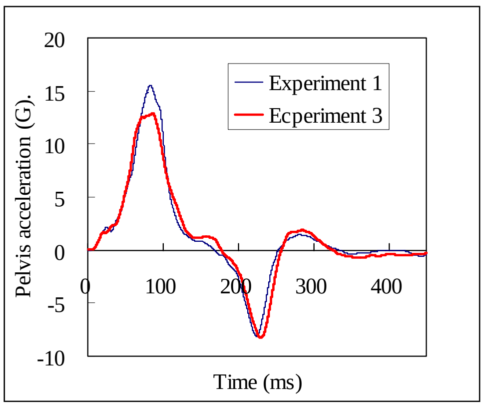


Figure 6. Time histories of the acceleration of the pelvis of the dummy (with seatbelt)

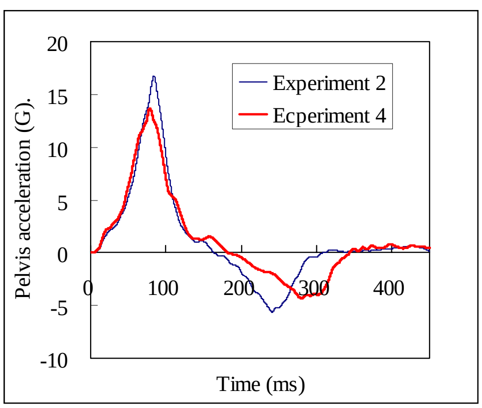


Figure 7. Time histories of the acceleration of the pelvis of the dummy (without seatbelt)

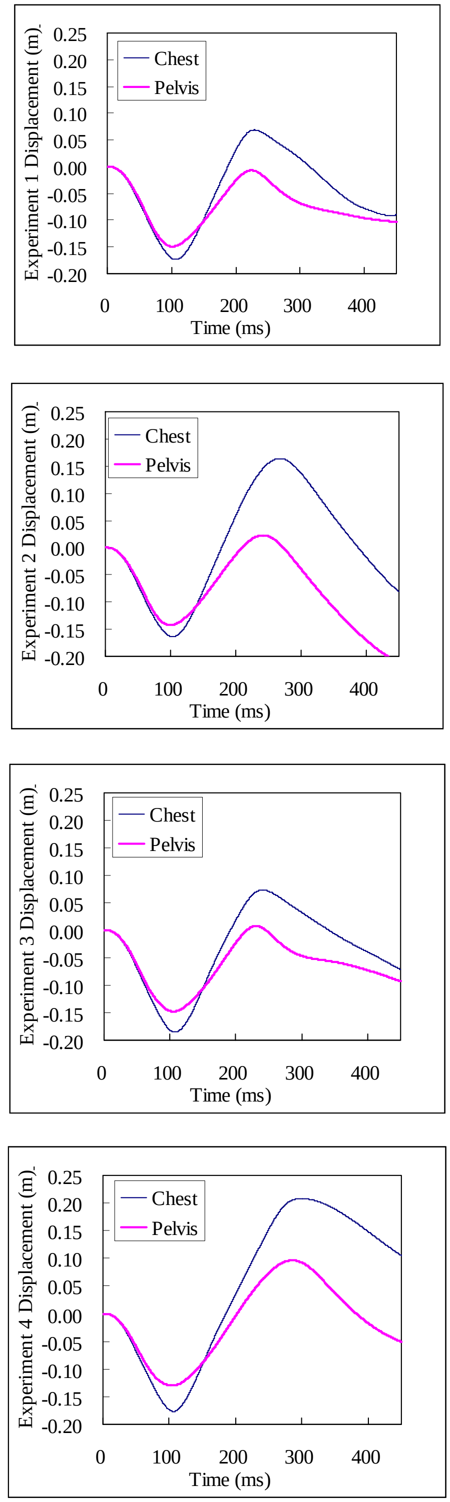


Figure 8. Time histories of the displacement of the pelvis and the chest of the dummy relative to the sled setup

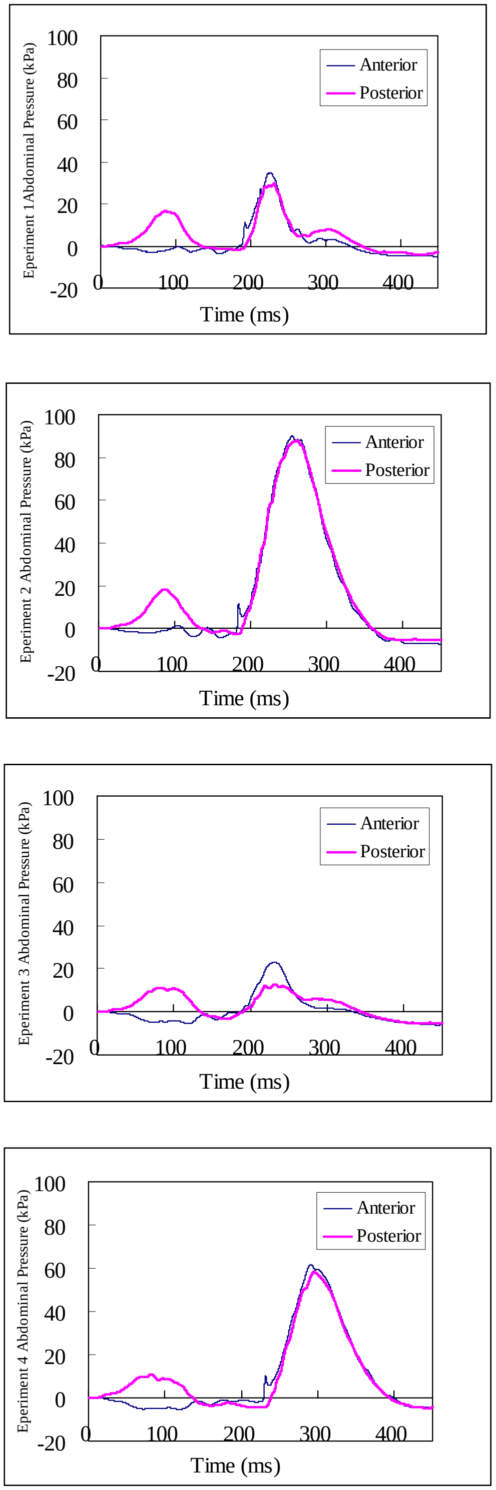


Figure 9. Time histories of the pressure of the abdominal bladder of the dummy

In the experiment 1 (MVSS setting with seatbelt), after the backward movement of approximately 150mm during 100ms from the start of the impact, the dummy commenced moving forward due to rebound. After that, the superior part of abdomen came in contact with the steering wheel at the time of 190ms.

In the experiment 2 (MVSS setting without seatbelt), the backward movement similar to that of the experiment 1 was observed. However, the abdomen came in contact at the time of 180ms, the chest and the head came in contact with the steering wheel at the time of 250ms from the start of the impact.

In the experiment 3 (volunteers setting with seatbelt), the dummy moved forward due to rebound, however, it moved downward in the most forward position of the movement. The contact between the dummy and the steering wheel was not observed finally.

In the experiment 4 (volunteers setting without seatbelt), the abdomen came in contact at the time of 230ms, however, the chest and the head did not come in contact with the steering wheel finally.

DISCUSSION

The results of the measurement showed correlation between the horizontal distance from the steering wheel to the abdomen and the height of the subjects. Furthermore, a verification of the second impact was conducted using AF5th percentile dummy.

As noted previously, the MAMA-2B was developed based on the Hybrid-3 AF5th percentile dummy, which is basically for the measurement apparatus for the injury indices during frontal impact. However, this study focused on the entire kinematics of the pregnant drivers especially the second impact due to rebound. Therefore, the examination using the MAMA-2B was deemed appropriate.

The seat slide position of the MVSS setting is forward in 40mm from that of the volunteers setting. Between the two settings, there was a difference of 100mm in the horizontal distance from the steering wheel to the abdomen and of 8° in the reclining angle. The difference in the contact of the abdomen was observed in the comparison between the experiment 1 and 3. The differences in the kinematics of the upper torso, the contact of the head and the chest were observed in the comparison between the experiment 2 and 4. The results showed that the kinematics and the second impacts were affected by the seating posture of the dummy; the appropriate setting methodology for the pregnant dummy will be an issue to be discussed.

In the time history of the posterior part of the abdominal pressure, the primary peak value was observed at the time of 100ms from the start of the impact i.e. in the most backward position of the dummy during impact. This response showed good match with the time history of the acceleration of the pelvis. Furthermore, the secondary peak value was observed at the time of 200ms where the dummy came in contact with the steering wheel. The anterior part of the abdominal pressure, on the other hand, indicated slight negative value during backward movement of the dummy. The peak value was observed at the time where the dummy came in contact with the steering wheel as well as the posterior part of the abdominal pressure. From these observations, in the mechanism of the primary peak value, the inertial loading was dominant, and in the mechanism of the secondary peak value, the abdominal compression by the steering wheel and the lumber spine was dominant. In the experiment, it was also observed that the steering lower rim came in contact to the inferior sternum, i.e. the fundus of the bladder. Previously, Rupp et al. derived the correlation between the peak anterior part of the abdominal pressure and the adverse feral outcome with actual case analysis and frontal impact experiments using the MAMA-2B.（6）In the study, because only the anterior part of the abdominal pressure was evaluated, the experiments were conducted using rigid seat, consequently the lower steering rim stably compressed the abdomen of the dummy on the umbilicus level. Therefore in this study, we further measured the posterior part of the abdominal pressure to precisely evaluate both direct and inertial loading of the abdomen.

CONCLUSION

Based on the seating posture determined by the measurement of pregnant volunteers in an actual passenger vehicle, a series of rear impact sled tests were conducted by using a pregnant dummy representing 30 weeks of gestation. The responses and its kinematics were examined.

From the results of the measurement showed somewhat strong correlation between the horizontal distance from the lower rim of the steering wheel to the abdomen and the height of the pregnant drivers.

The kinematics and the second impacts were affected by the difference in the seating posture in the experiments both with and without seat belt.

The time history of the anterior part of the abdominal pressure showed a peak value due to the second impact loading, however, the posterior part of the abdominal pressure showed primary peak value due to inertial loading and secondary peak value due to the second impact loading.

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