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Shorter pregnant women restrained in the rear seat of a car are at risk for serious neck injuries: Biomechanical analysis using a pregnant crash test dummy☆

Masahito Hitosugi[a,*], Takeshi Koseki[a,b], Tomokazu Hariya[a], Genta Maeda[a], Shingo Moriguchi[a], Shiho Hiraizumi[a]

[a] Department of Legal Medicine, Shiga University of Medical Science, Otsu, Shiga 520-2192, Japan
[b] Department of Obstetrics and Gynecology, Tsukuba Memorial Hospital, Tsukuba, Ibaraki 300-2622, Japan

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ABSTRACT

Introduction: When considering seat belt contacts to the neck in pregnant woman of shorter height sitting in the rear seat of a vehicle, subsequent injuries after a collision must be understood in the context of both maternal and fetal outcomes. To determine likely injuries to a pregnant woman sitting in the rear seat, we determined the kinematics of a "pregnant" crash test dummy by measuring neck compression forces and biomechanical parameters acting on the head and neck.
Methods: Sled tests using a shorter-height pregnant woman crash test dummy (Maternal Anthropometric Measurement Apparatus, ver. 2B) were performed at the HYGE sled test facility representing full frontal impact at target velocities of 29 km/h and 48 km/h. Kinematics of the dummy and biomechanical parameters of the head, neck, and chest were measured. Pressure to the neck was measured using Prescale (Fujifilm, Tokyo, Japan).
Results: During frontal collision tests, the shoulder belt compressed the neck at a pressure >12.8 MPa, even during the low-velocity impact. In addition to neck flexion, right side bending and the head and chest moving in opposite directions were observed, with maximum differences of 42.4 mm at high velocity and 33.7 mm at low velocity.
Conclusions: This study provides data on the kinematics of pregnant women of short height sitting in the rear seat during a frontal collision using a pregnant woman crash test dummy. The knowledge gathered from this study should be useful for determining pregnant women passengers' kinematics at the time of collision and evaluating the relationship between the vehicle collision and fetal outcomes.

1. Introduction

Motor vehicle collisions (MVC) are a leading cause of death globally, resulting in 1.2 million deaths every year [1]. In aiming to reduce fatalities in MVCs, thorough analyses of victims' injuries and effective interventions are required. In practical forensic medicine, by reconstructing the collision we can obtain a deeper understanding of the relationship between applied forces and injuries, as well as kinematics of the victims. Indubitably, pregnant women are sometimes involved in MVCs. Conolly et al. report that 6%–7% of pregnant women are subject to some form of traumatic injury during pregnancy, and approximately two thirds are because of MVC [2]. Although the exact number of pregnant women who are injured is unknown, a recent study in Japan involving pregnant women at 35–37 weeks gestation suggested that 2.9% had experienced a MVC as an occupant during their current pregnancy [3]. Negative fetal outcomes have often been observed among the pregnant women involved in MVCs. According to a study of maternal traffic injuries and their fetal outcomes, the women who had suffered from direct external forces to the abdomen or lumbar region, or from high Abbreviated Injury Scale score of abdominal injuries, more frequently experienced fetal deaths [4]. At the compensation hearing, as the offenders' responsibilities for both maternal and fetal outcomes are discussed, forensic scientists need to understand the kinematics and subsequent injuries of the pregnant women passengers during a collision.

For vehicle passengers, safety devices such as seat belts and airbags also influence the mechanisms of injuries. The use of a seat belt reduces the risk for fatal injuries for pregnant women and the fetus

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* Corresponding author at: Department of Legal Medicine, Shiga University of Medical Science, Tsukinowa, Seta, Otsu, Shiga 520-2192, Japan.
E-mail address: hitosugi@belle.shiga-med.ac.jp (M. Hitosugi).

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during impact [5–7]. We previously studied seat belt–neck contact during the late term of pregnancy by measuring seating postures of rear seats [8]. Because vital structures such as jugular veins, common carotid arteries, and the vagus nerve are at the front–lateral side of the neck, neck injuries may occur during a frontal collision. However, there have been no reports examining the kinematics and injuries of pregnant women passengers with seat belt–neck contact.

To understand the kinematics of pregnant women of diminished height sitting in rear seats during a frontal collision and the consequent likely injuries, we performed sled tests and measured neck compression forces and biomechanical parameters acting on the head and neck using a pregnant crash test dummy.

2. Methods

2.1. Pregnant crash test dummy

The dummy used in sled tests was the latest version of the maternal anthropometric measurement apparatus, ver. 2 B (MAMA-2B), which is based on the Hybrid-III American female 5th percentile dummy [9,10]. This dummy was developed to analyze the kinematics of pregnant women and the consequences of an impact on the fetus during a MVC. The risk for adverse fetal outcomes by simulating loading and boundary conditions mimicking real-world accident conditions have been reported [6]. The pelvis, sternum, and ribcage were modified to accommodate a silicon rubber bladder, representing the uterus at 30 weeks gestation. The height of the dummy was 153 cm and was similar in height to shorter pregnant women in whom the seat belt and neck make contact (mean height: 152.3 cm) [8].

2.2. Seat belt path

The seat belt path across the dummy before testing was observed to make contact with the neck. The shoulder strap was positioned on the left side and was placed so that it avoided the protruding abdomen. The distance between the chin and the center of the shoulder strap was 111.0 cm.

2.3. Sled test

The seat used represented the right side of a rear seat of a typical mid-size passenger sedan, with a seat-back angle of 20°. The seat belt was applied to the dummy without a pre-tensioner or force-limiter. Sled tests were performed at the HYGE sled test facility in accordance with previously published protocols [11]. Two test conditions were set: full frontal impact at target velocities of 29 km/h and 48 km/h. Acceleration pulses (crash pulses) in each condition were applied as previously reported. Two tests at each velocity were performed. Kinematics of the dummy, such as trajectory during impact, were examined using high speed video imaging. Head and chest acceleration in each direction, head moments in each direction, tension and compression forces on the neck and neck acceleration in each direction, and displacement of the chest and head were measured. These parameters were measured using devices installed on the dummy that were compliant with Federal Motor Vehicle Safety Standards and Regulations.

2.4. Injury criteria

Injury criteria were assessed using measured values. The head injury criterion (HIC) was used to assess the head injury potential based on resultant translational accelerations of the head [12]. Maximum time for calculating HIC was determined as 15 m/s. The neck injury criterion (N_{ij}) was developed for frontal impact [13]. N_{ij} included the four neck injury predictors: N_{TE} (tension–extension), N_{TF} (tension–flexion), N_{CE} (compression-extension), and N_{CF} (compression-flexion). Chest acceleration was determined by the peak value with a 3 m/s duration. These criteria were compared with injury assessment reference values (IARV) for a dummy of the same size as that used in the tests [14]. The IARV have safety thresholds corresponded to Federal Motor Vehicle Safety Standard 208.

2.5. Contact pressure

Pressure to the neck during the sled test was measured using Prescale (Fujifilm, Tokyo, Japan). Prescale is a film that measures pressure and pressure distribution. Areas where pressure is applied become red in response to pressure, and the pressure magnitude is shown by changes in color density. The film was attached to the front right side of the neck, where the shoulder strap may make contact.

3. Results

3.1. Kinematics of the dummy

A representative image of the kinematic sequence showing changes in dummy position during high-velocity impact is shown

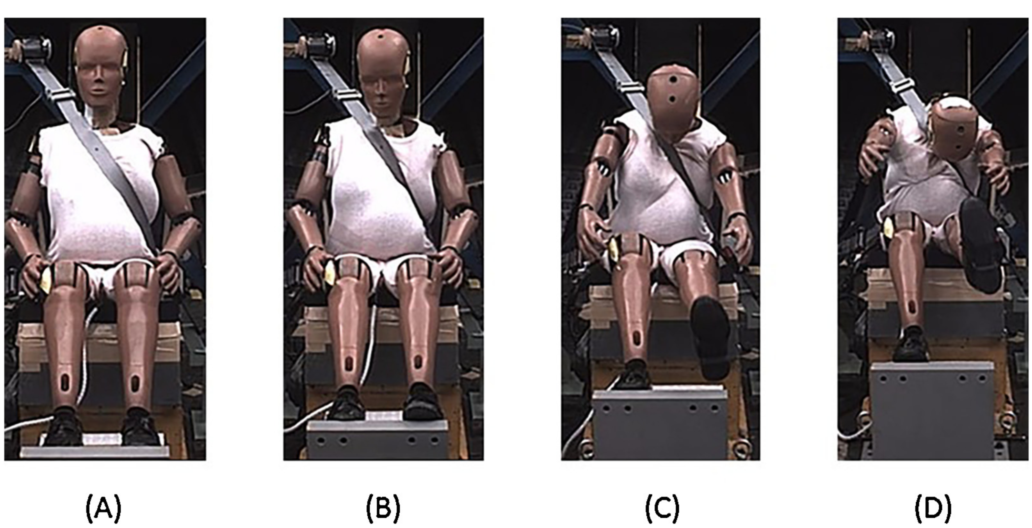

Fig. 1. Kinematic sequence showing the position of the dummy during a high-velocity impact A: 40 m/s, B: 60 m/s, C: 80 m/s, D: 100 m/s after impact initiation.