EFFECT OF INCLUDING A FETUS IN THE UTERUS OF PREGNANT WOMEN OCCUPANT MODEL IN CRASH TEST SIMULATIONS

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ABSTRACT

Motor vehicle accidents are the largest single cause of accidental death and the leading cause of traumatic injuries for the pregnant occupant and her fetus. Computational pregnant occupant modelling has a role to play in the investigation of the risk of fetal injuries and mortality in crash test simulations. Effective investigation depends on realistic representation of pregnant occupant and her fetus in a virtual environment. However, known pregnant occupant models normally do not include a fetus in the uterus. 'Expecting', the first computational model of a pregnant occupant with a fetus, is used in the current research. The model has a detailed multi-body representation of the fetus as well as a finite element uterus and placenta.

In this paper, the effect of including the fetus in the uterus of the pregnant occupant model is investigated using 'Expecting' in crash test simulations. Previously, drop test simulations with and without a fetus showed that, the presence of fetus in the uterus suggests higher risks to the fetus. Using the pregnant occupant model, 'Expecting', with and without a fetus, provides more realistic simulations to explore the role of including a fetus in the uterus. Five frontal impact speeds, 15, 20, 25 30 and 35 kph with varying levels of restraint system including 'seatbelt and airbag' (ie fully restrained), 'seatbelt only', 'airbag only' and 'no restraint' are used in the simulations. Maximum strains developed in the uteroplacental interface with and without a fetus are compared. The effect of including a fetus in the pregnant occupant model is discussed.

INTRODUCTION

The separation of the placenta from the wall of the uterus due to vehicle accidents is the leading cause of fetal death accounting for 50-70 % of all losses (Pearlman et al., 1990). Pregnant occupant should always wear the three-point safety seatbelt correctly in order to minimize any potential trauma from a car accident. This is a legal requirement in many countries. However, discomfort and the false belief that the seatbelt may put the fetus in danger in case of a crash, lead some pregnant occupants not to wear the seatbelt. This, of course, could cause a serious safety problem for pregnant women and her unborn baby.

Computational modelling and crash test simulations offer an alternative but effective solution to anthropomorphic test devices (ADTs) to investigate occupant safety in motor vehicles. Realistic modelling and simulation of pregnant women in crash tests play a significant role in the investigation of potential injuries to the pregnant occupant and her fetus in vehicle accidents, as realistic pregnant ADTs are not commonly available. The first computational pregnant occupant model with a fetus, 'Expecting', which has a detailed multi-body representation of the fetus as well as finite element uterus and placenta, was developed at Loughborough University.

Previous computational pregnant occupant models were designed without fetus. The decision not to include a fetus in the pregnant occupant model was based on the findings of (Rupp et al. 2001), which concluded that the inclusion of a fetus in the uterus did not make a significant difference. Their research, which included vertical drop simulations of fetus and uterus model onto a rigid flat surface at different angles of orientation, is repeated with the uterus of 'Expecting', the pregnant occupant model, with and without a fetus by Acar et al. (2012). The drop test simulation results showed that the existence of a fetus in the uterus has a significant effect on the strain levels in the uteroplacental interface (UPI), with the exception of 90-degree orientation, where the difference was small.

This study, further investigates the implications of including a fetus in the uterus with the whole 'Expecting' model in crash test simulations. A number of simulations with and without fetus is conducted including 'full restraint', 'airbag only', 'seatbelt only' and 'no restraint' at different crash speeds. The effect of the inclusion of the fetus in the model on the strains generated at the uteroplacental interface is discussed.

METHODOLOGY

The research strategy adopted in this study is to use the current 'Expecting' pregnant occupant model in order to represent a realistic pregnant occupant model, which has a fetus in the uterus. Then, a version of the 'Expecting' model without a fetus, where the uterus is filled with amniotic fluid only, is developed. Both with a fetus in the uterus and its without-fetus version are used to investigate the contribution of the inclusion of a fetus on the strains generated at the uteroplacental interface, in a number of crash test simulations.

'Expecting' is a 5th percentile female in her 38th week of pregnancy. A detailed multi-body representation of a 3.3 kg fetus consisting of 15 rigid bodies and respective joints within a finite element uterus model is integrated into the computational pregnant woman model, which is generated by modifying an existing small female model using the anthropometric pregnant women data. The model was generated in the multi-body/finite element software package MADYMO of TNO Automotive. The development and validation phases of Expecting can be found in Acar and Lopik, (2006). Expecting is illustrated in Figure 1.

In the 'Expecting' witout-fetus model, the entire uterus is filled with the amniotic fluid, which is 98-99% water and hence can be considered as incompressible. In the with-fetus model, the 38 weeks old fetus almost fills the entire volume of the uterus leaving minimal space for the amniotic fluid. The material properties of the uterus, placenta, fat tissue and amniotic fluid, as used by the previous researchers, are given in Table 1.

Table 1. Material properties used in the model

Structure	Material Model	Young's Modulus (kPa)	Density (kg/m^3)	Poisson's Ratio
Uterus	Linear elastic	566	1052	0.4
Placenta		63	995	0.45
Fat		47	993	0.49
Amniotic Fluid		20	993	0.49

Simulation Set-up

'Expecting', the pregnant occupant model and its without-fetus version are used in identical crash test simulations. These include (i) 'seatbelt & airbag', representing a properly restraint pregnant driver; (ii) 'seatbelt only' excludes the airbag; (iii) 'airbag only' excludes the seatbelt, but yet the airbag is active; and finally (iv) 'no restraint' excludes all restraints, in other words neither the seat belt is worn nor the airbag is deployed. For each case, tests are run with crash speeds of 15, 20, 25, 30 and 35 kph, and the acceleration pulses applied to the model are half-sine waves with 120 ms duration as shown in Figure 2.

Injury Criteria

Maximum von Mises equivalent strain levels in uterus at placental location (utero-placental interface (UPI)) are determined for with and without fetus models to assess the possibility of placental abruption, which is the main cause of fetal and occasionally maternal fatalities. The threshold strain value for the occurrence of placental abruption is widely accepted to be 0.60 at the UPI (Rupp et al., 2001).

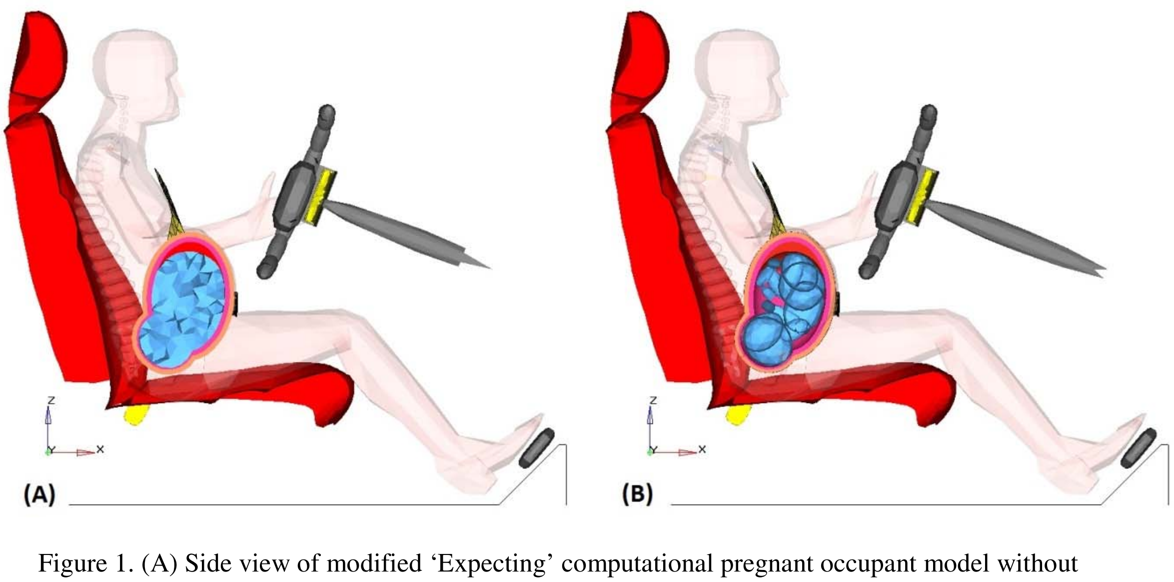

Figure 1. (A) Side view of modified 'Expecting' computational pregnant occupant model without fetus and (B)'Expecting' (with fetus)

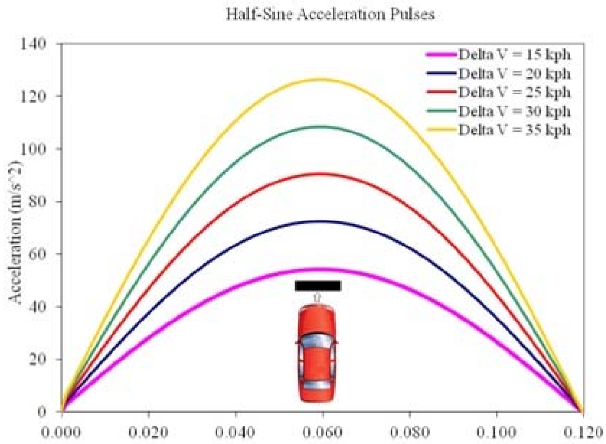

Figure 2. Half-Sine Acceleration Pulses

RESULTS AND DISCUSSIONS

Strains in the uterus at placental location are investigated to highlight the fetal injury risk. Figure 3 depicts visually a typical impact response at 30 kph for the fully restraint ('seatbelt & airbag') occupant with and without a fetus. Figure 3 (a) clearly shows the excessive deformations on the uterus due to fetus loading, whereas the without fetus case shows less severe deformations.

In general, the maximum strain levels at the utero-placental interface increase with crash speed as expected. The maximum strain in the with-fetus model is typically higher than the strains in the without-fetus model, indicating a greater risk of placental abruption.

Figure 4 compares the strain levels for the 'seatbelt & airbag' case for a crash speed range of 15-35 kph. The without-fetus model simulation results show lower strain levels than with-fetus model simulations up to the 35 kph. Figure 4 shows that maximum strains at the UPI for the with- and without-fetus models vary between 0.24 to 0.42 and 0.18 to 0.42 respectively. The increase for without fetus case is gradual and almost linear, whereas for the with fetus case, there is a greater increase in strain from 15 to 20 kph. All strain values at the UPI are considerably below the injury threshold value of 0.60.

The 'seatbelt only' case results for the maximum strains at the UPI are shown in Figure 5, which follows a similar pattern to the strains in the 'seatbelt & airbag' case, but are generally higher. At 35-kph impact, the strain level approaches the placental abruption risk threshold of 0.60 for both cases. The higher strain levels could be attributed to the pressure that the steering wheel applies to the uterus at the anterior edge of the placental location forcing the fetus downwards. However, the lap portion of the three-point seatbelt prevents the occupant moving excessively forward. The placenta is also compressed between the fetus and steering wheel in the with-fetus model and this dynamic motion generates considerably higher strains at the UPI than in the without-fetus model.

Figure 6 shows the maximum strain levels at the UPI for the 'airbag only' case which demonstrates that when the fetus is included in the model, the placental abruption risk emerges at a crash speed of 20 kph, whereas the without-fetus model shows that the placental abruption risk begins at a higher crash speed of 30 kph. Without the seatbelt, it is clear that the contribution of the fetus on the maximum strains at the UPI is much more pronounced and the placental abruption risk is found to be higher. The significant mass of the fetus (3.3 kg) plays a significant role in the behaviour of 'Expecting', the pregnant occupant model. These results clearly demonstrate that the fetus changes the entire dynamic response to impact.

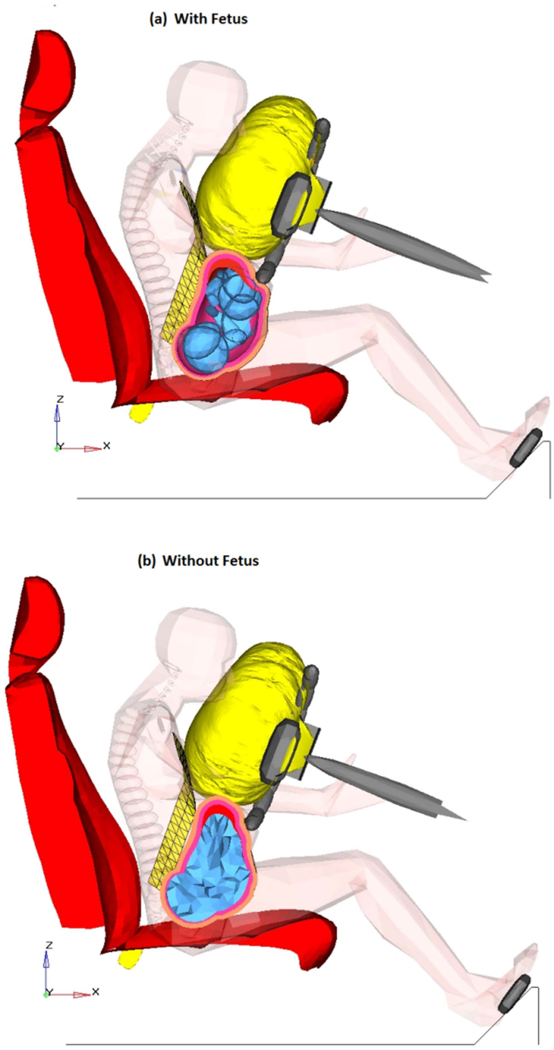

Figure 3. Typical frontal impact responses for 30 kph at 105ms of impact.

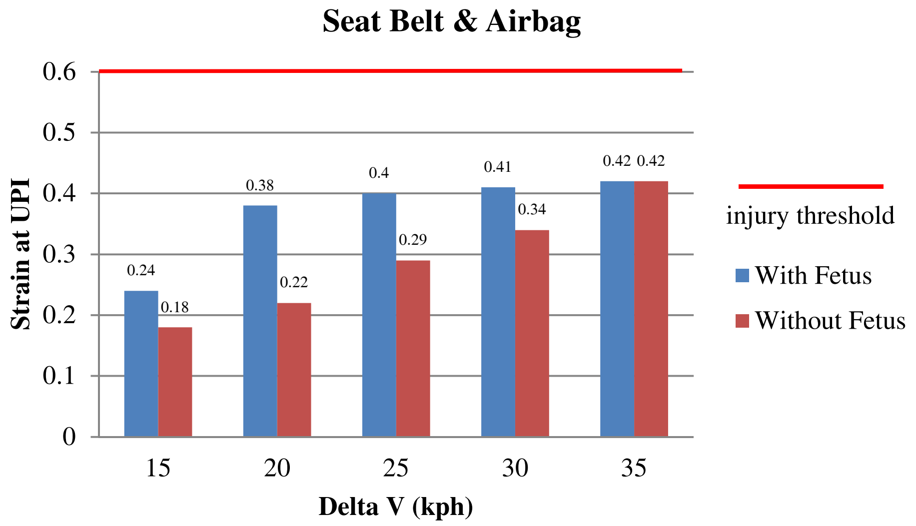

Figure 4. Maximum Von Mises strain at the UPI for the 'seatbelt & airbag' case.

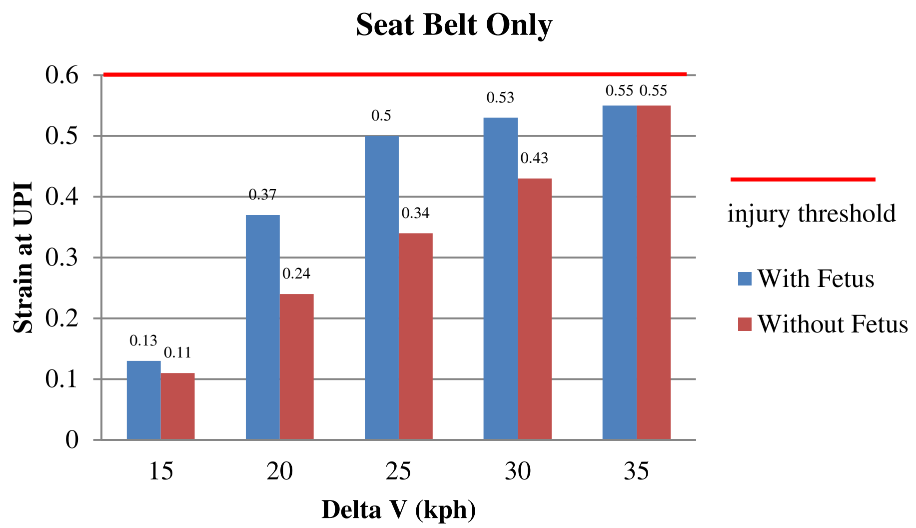

Figure 5. Maximum Von Mises strain at the UPI for the 'seatbelt only' case.

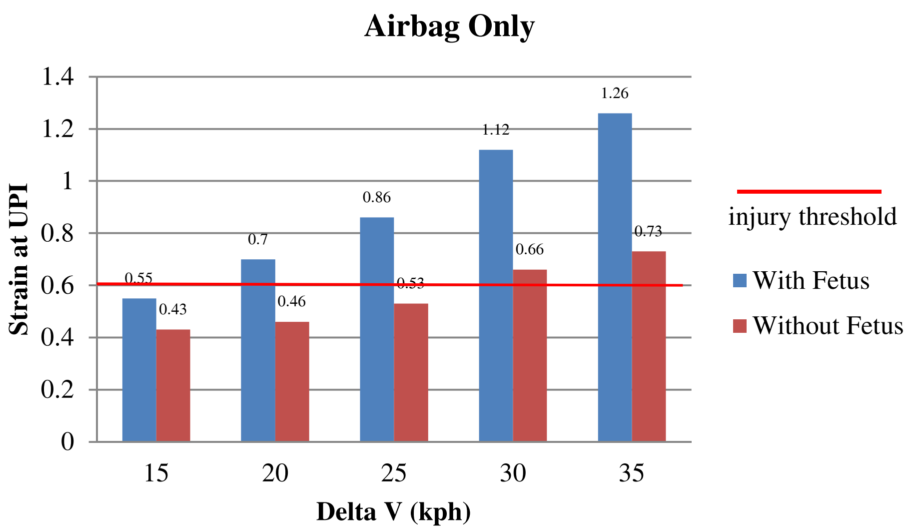

Figure 6. Maximum Von Mises strain at the UPI for the 'airbag only' case.

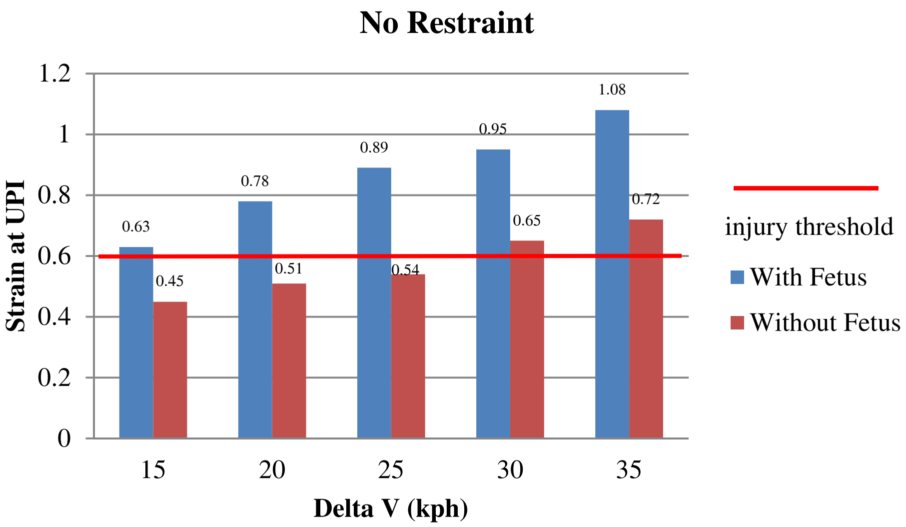

Figure 7. Maximum Von Mises strain at the UPI for the 'no-restraint' case.

For the 'no-restraint' case shown in Figure 7, the with-fetus model, shows placental abruption risk at all speeds considered (15-35 kph), whereas in the without-fetus model, strains at the UPI are below the injury threshold value of 0.60 for at 15, 20, and 25 kph.

The simulation results clearly demonstrate that the use of seatbelt in conjunction with the airbag is essential for the protection of the fetus in vehicle crashes.

CONCLUSIONS

In this research, implications of including a fetus in the uterus of 'Expecting', the pregnant occupant model, are investigated. 'Expecting' with and without fetus model is used to simulate a range of frontal impacts of increasing severity from 15 kph to 35 kph. Four cases of occupant restraint, seat belt and airbag, seat belt only, airbag only and completely unrestraint are investigated. In crash simulations, the loading from the seatbelt, steering wheel and airbag, causes strains to develop in the uterus. When the fetus model is included in the uterus, inertial loading on the uterus due to the motion of the fetus occurs too.

Crash test simulation results from the 'Expecting', the pregnant occupant model, show that the inclusion of the fetus in the model creates a more realistic representation of the pregnant occupant, which changes the dynamic response of the model in crash simulations. Inertial effects on the fetus cause it to move forwards relative to the pregnant occupant. The fetus accelerates towards the anterior wall of the uterus. Consequently, this dynamic motion of fetus generates significantly higher strains at the UPI than without fetus model. Therefore, fetus should be included in the uterus in pregnant woman models for realistic results in crash test simulations.

REFERENCES

Acar, B. S., and van Lopik, D., (2009), "Computational pregnant occupant model, 'Expecting', for crash simulations", *Proc. IMechE Part D: J. Auto Engineering*, 223, pp. 891-902.

Acar, B. S., and Weekes, A. M., (2004), "Designing for safety during pregnancy through a system for automotive engineers", *International Journal of Crashworthiness*, 9(6), pp. 625-631.

Pearlman, M.D., Tintinalli, J.E., and Lorenz, R.P. (1990) "Blunt trauma during pregnancy". *New Eng. J. Med.*, 323(23), 1609-1613.

Rupp, J. D., Schneider, L. W., Klinich, K. D., Moss, S., Zhou, J., and Pearlman, M. D. (2001), "Design, development, and testing of a new pregnant abdomen for the Hybrid III small female crash test dummy", *Report UMTRI-2001-07*, Ann Arbor, Michigan, USA.

Acar, S., Moustafa M., and Acar, M., Implications of including a fetus in the uterus of pregnant woman model, *The Proceedings of ICrash 2012,* July 18-2-. 2012, Milano, Italy