

# THE EFFECT OF PLACENTA LOCATION ON THE SAFETY OF PREGNANT DRIVER AND HER FETUS

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## ABSTRACT

Placental abruption accounts for more than half of fetal mortality in automobile collisions. In most of the pregnancies, placenta is located at the fundus position of the uterus. However, in real life, placenta can also be found at different locations in the uterus.

The goal of this study is to investigate whether the location of the placenta in the uterus of pregnant driver has a role on the risk of placental abruption in motor vehicle accidents. In addition to the most common fundus position, four other placental locations namely, anterior, posterior, lateral left and lateral right, are considered within the computational pregnant driver model 'Expecting', and used in collision simulations with impact severities from 15 kph to 30 kph with 5kph increments. Scenarios also include four cases where the pregnant driver is fully restrained with three-point seatbelt and airbag, three-point seatbelt only, airbag only and no-restraint at all. The maximum strains developed in the utero-placental interface (UPI) of the model in this set of 64 simulations together with the fundus-location simulations are determined and compared in order to investigate the effect of placental location on the placental abruption prediction.

Placenta located at anterior position is found to be at higher risk than other placental positions considered in this investigation. The results demonstrate that being fully restrained is the safest option and the three-point seatbelt is the most effective restraint system whilst the airbag makes a small contribution to the protection of pregnant driver and her fetus.

Keywords: Pregnant, Placenta, Driver, Fetus, Crash, Safety, Modelling, Simulations.

## 1. INTRODUCTION

Road traffic accidents are the largest cause of accidental fatality and the leading cause of traumatic injuries for pregnant occupant and her fetus (Pearlman [9] and Weiss [16]). Understanding the injury mechanisms of pregnant women and their unborn baby is crucial to improving their safety in road traffic accidents. However, investigations into the cause of maternal and fetal injuries and fatalities following traffic accidents are limited.

Whilst uterine rupture is a rare condition occurring in less than 1 % of pregnant trauma cases, placental abruption is the most common cause of fetal loss in motor vehicle accidents and accounts for around 50-70 percent of all fetal mortality (Rupp et al, [13]). Placental abruption occurs where the placenta becomes partially or completely detached from the inner surface of the uterus wall. This disrupts the supply of oxygen and nutrients to the fetus and leads to fetal loss and poses a hazard for the pregnant woman as well. Tissue characteristics of uterus and placenta are different therefore an impact on the abdomen would induce different strain levels on the uterus and placenta at the utero-placenta interface

(UPI). This may lead to placental abruption, in other words the separation of the two structures hence, leading to fetus mortality. In order to determine critical strains for placental abruption, shear and uniaxial tensile testing of placenta and uterus were conducted (Pearlman et al, [10] ). It is widely accepted that placental abruption occurs if the strain value at the UPI exceeds 0.60.

The general anatomy of the pregnant abdomen is complicated. The abdomen may be different not only from one woman to another but also from one pregnancy to another for the same woman. In approximately 80 % of pregnancies, the placenta is located in the upper region (fundus) of the uterus (Pepperell et al, [12] ) hence the previous studies focused on the fundus location of the placenta only (Rupp et al, [11] and Acar and Esat [3] ) However, placenta can be attached anywhere on the inner surface of the uterus wall, such as anterior or posterior, lateral left or lateral right. Placenta may also be attached to the uterine wall covering cervix however, this is very rare, occurring in less than 1% of all pregnancies.

The aim of this study is, therefore, to investigate whether the location of the placenta in the uterus of pregnant driver has a role on the risk of placental abruption in motor vehicle accidents.

## 2. METHOD

This research considers different placental locations within the 'Expecting' computational pregnant driver model of Acar and van Lopik [4] with a fetus to predict strain levels at the UPI, which is taken as the measure of placental abruption risk. A range of frontal impact conditions with varying severity and restraint system combinations were simulated in order to estimate the risk of placental abruption in motor vehicle accidents. The maximum von Mises equivalent strain level at the UPI was used for this purpose. Strain levels at UPI for the four different placental locations were then compared with the UPI strain levels of the original 'Expecting' studies in Acar and Esat [1], [2], where the placenta was at the fundus position.

### 2.1. Computational Pregnant Model: 'Expecting'

A computational model of pregnant occupant without a fetus was used for the analysis of restraint effectiveness in Moorcroft et al [8]. On the other hand, 'Expecting', an anatomically realistic computational model of a pregnant woman as a driver in her 38<sup>th</sup> week of pregnancy was developed including a multibody fetus within a finite element uterus (Acar et al [6] and Acar and Weekes [7]). It was created in the multibody/finite element software package MADYMO of TNO Automotive [15]. FE uterus containing the multibody fetus was integrated with the 5<sup>th</sup> percentile pregnant woman's body. 'Expecting' is illustrated in Figure 1 together with the uterus containing fundal placenta and the fetus.

Further details of the computational modelling and validation of 'Expecting' using the rigid bar and belt loading tests can be found in Acar and van Lopik [4]. Details of the development of the 38 week old fetus can be found in Acar and van Lopik [5].

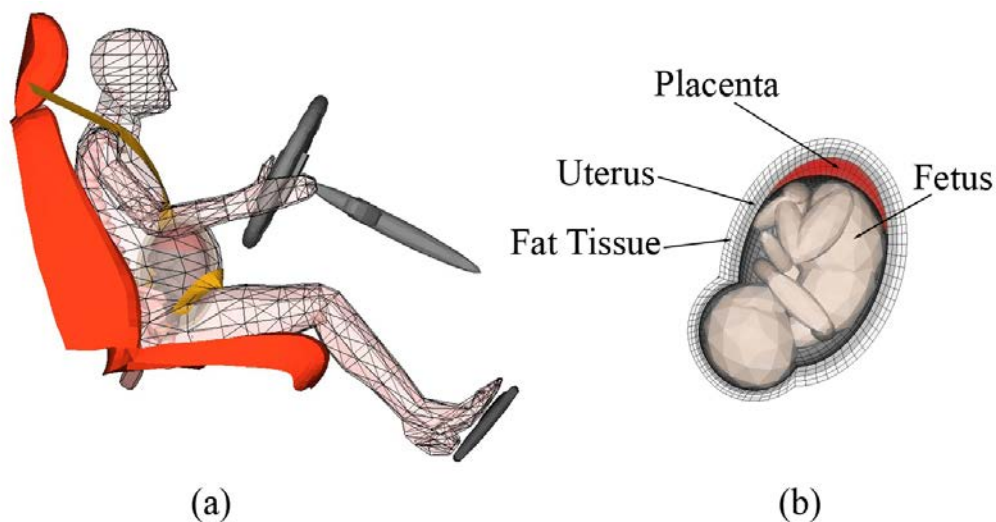


Fig. 1. The pregnant occupant model 'Expecting' (a); and uterus, placenta in the fundus position and fetus as used in 'Expecting' (b).

## 2.2. Placental Locations in the Uterus

The locations of placenta in the uterus can be determined by ultrasonography. Anywhere on the inner surface of the uterus wall is a possibility for placental location. However, in majority of pregnancies the placenta is situated at the top of the uterus, called the fundal placenta. Other locations may include the front wall of the uterus (the anterior placenta), the back wall (the posterior placenta) as well as the side walls (lateral left and lateral right placenta), as shown in Figure 2

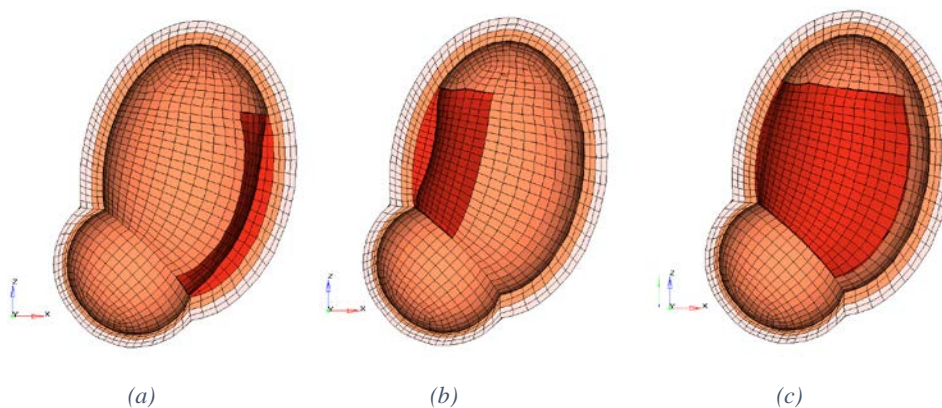


Figure 2. Side views for (a) Anterior, (b) Posterior and (c) Lateral right placenta within the uterus of the 'Expecting' model (Lateral left - not shown - is the symmetric version of lateral right).

## 2.3. Placenta Modelling

The shape of the placenta can be approximated to a flattened discoid, with an average mass of 470 g, volume of approximately 500 ml (Stranding [14]). The fundal placenta in 'Expecting' was positioned at the upper region (fundus) of the uterus and attached to uterine wall which has a thickness of 10 mm. The placental diameter was 185 mm with a thickness of 4 mm at edges and 20 mm in the centre. Surface area of the placenta was 26866 mm<sup>2</sup> at the utero-placental interface (UPI). The placenta was

modelled as elastic isotropic solid material; its properties were taken from Pearsall and Roberts [11], having a Poisson's ratio of 0.49, Young's modulus of 47kPa and a density of 0.995kg/dm<sup>3</sup>.

The placenta geometry was meshed using HyperMesh software package. In the meshing process, two layers of elements were generated. Placental outer surface and the inner surface of the uterus were mapped to create the placental elements at the interface (Acar and van Lopik, [4], [5]). Solid 8-noded brick elements were used to represent the placenta. Utero-placental interface consists of mutual nodes. The 3D placenta model was represented by 884 elements (Figure 3). Node coordinates and element configurations were exported into MADYMO.

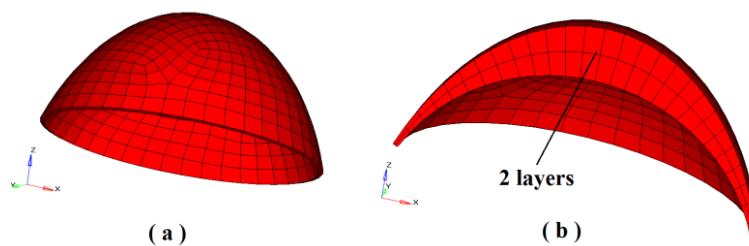


Figure 3. Meshed placenta; (a) Isometric view, (b) Cross-section view

Anterior, posterior, lateral left and lateral right placenta models were also generated by using Solid Edge CAD software suitable to map to the inner uterus geometry which was used as the base element and hence the mesh pattern of the uterus was not modified. It was not possible to maintain the discoid shape due to the mesh pattern of the inner uterus at the four new placental positions investigated. Hence, rectangular-shaped placenta models were generated at the four identified locations in the uterus model. The volume and the interface area of the placenta were kept as close as possible to the original fundal placenta to make comparison possible. Thickness of the placenta was non-uniform, similar to the original placenta in 'Expecting', and varies from 3 mm at edges to 20 mm in the centre. This model is created from two layers of 8-noded hexahedral elements. Placentas were meshed using HyperMesh (Altair).

## 2.4. Simulation Set-up

The 'Expecting' pregnant driver models with four different placental locations were used in simulations with a range of restraint combination at varying levels of impact severity. The parameters used in the simulations are as follows:

Placental locations:

- Anterior
- Posterior
- Lateral left
- Lateral right

Occupant restraint combinations:

- Seatbelt and airbag
- Seatbelt only
- Airbag only
- No-restraint

Impact severities:

- 15 kph
- 20 kph
- 25 kph
- 30 kph

The acceleration pulses applied to the model were half-sine waves with 120 ms duration.

In each case, the strains developed at the UPI were investigated and compared with those at fundus placental position.

### 3. RESULTS AND DISCUSSIONS

The maximum von Mises strains at the UPI for all the cases considered are shown in Figures 4,5,7 and 8. It can be seen that the strain levels at the UPI increases with increasing speed for all placental locations and for all restraint scenarios. However this increase is more pronounced with the placenta located in the anterior position, which generally has the highest strain levels, whereas the posterior placenta has generally the lowest strains.

#### 3.1 Fully restrained and seatbelt only cases:

When the pregnant driver is fully restrained, i.e. when both the seatbelt is worn correctly and airbag is deployed, the anterior placenta position at 30kph is the only case where the strain level at the UPI exceeds the threshold level of 0.60 for placental abruption (Figure 4). All other cases demonstrate strain levels safely below the threshold.

The simulation results with the seatbelt only case without the airbag deployment (Figure 5), a very similar trend to the fully restrained case is observed, again with only the anterior placenta location at 30 kph exceeding the strain threshold. It can be seen from Figures 4 and 5 that the lack of airbag deployment gives a slight rise to the strain levels in general. This demonstrates that the airbag makes only a small difference.

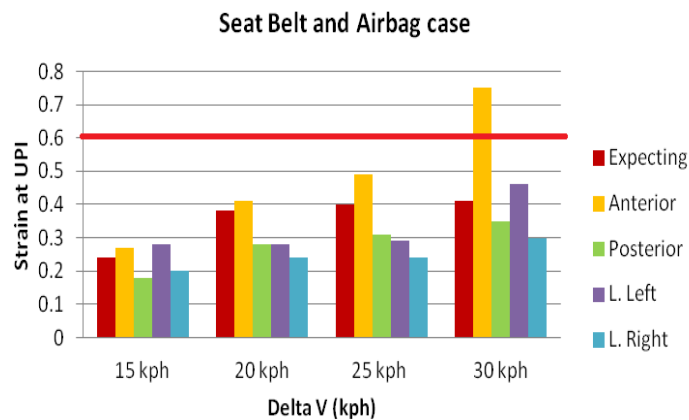


Figure 4 'Fully restrained' case - maximum Von Mises strains at the UPI for the placental locations and crash severities considered

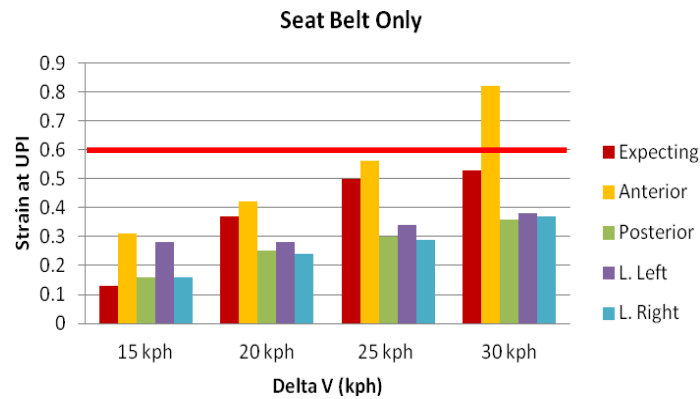


Figure 5. 'Seatbelt only' case - maximum Von Mises strains at the UPI for the placental locations and crash severities considered

In both cases, the high strain levels for the anterior placenta can be attributed to the lap belt compression. As depicted in Figure 6 the placenta located at the anterior position within the uterus is effectively sandwiched between the belt and the fetus. Therefore, peak von Mises strains for the anterior placenta is always higher than placenta located at fundus or any other locations when the seatbelt is worn.

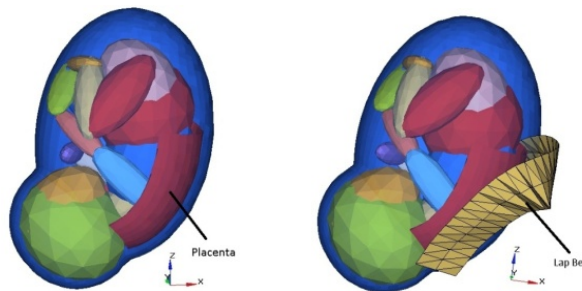


Figure 6. Placenta at anterior and fetus within uterus model.

### 3.2 Airbag only (no seatbelt) and no-restraint cases

The airbag only case (Figure 7) depicts similar results to the no-restraint case (Figure 8) with only slightly lower strain values at lower crash speeds, once again confirming that the airbag alone plays a very small role in the protection of the pregnant occupant. It also suggests that contrary to the common concern for pregnant women reported by Acar and Weekes [7], the airbags do not seem to pose further hazard for the fetus. The results also show that the UPI strain at the anterior location reach or surpass the threshold level during impacts from 20 kph. The UPI strain levels for the posterior placenta are found to be lower than the threshold levels at all crash severities suggesting that the posterior location is the safest for placental abruption risk because it is not subjected to any direct impact from the lap belt or steering wheel.

For the no-restraint case, when the placenta is located at the fundus position, the UPI strain levels are above the threshold value at all crash severities leading to placental abruption. This is attributed to the impact of the top of the uterus of the unrestrained occupant with the steering wheel.

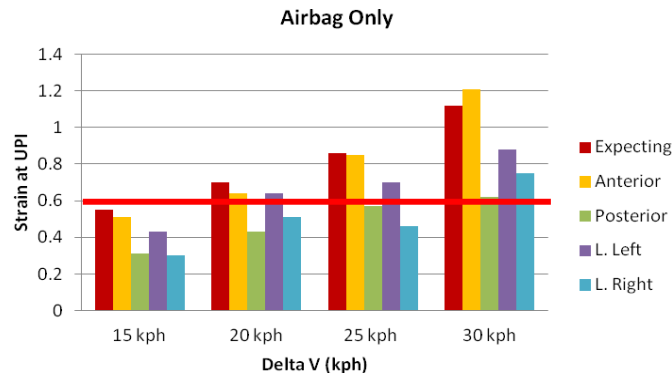


Figure 7. 'Airbag only' case, maximum Von Mises Strains At The Utero-Placental Interface Comparison For The Four Different Placental Locations

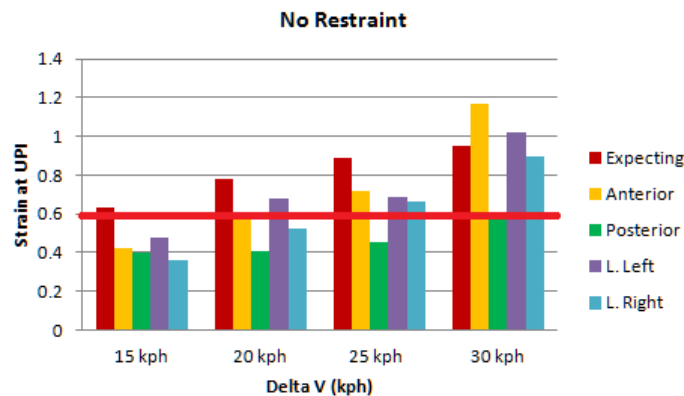


Figure 8. 'No-restraint' case, maximum Von Mises Strains At The Utero-Placental Interface Comparison For The Four Different Placental Locations

### 3.3 Lateral left and lateral right placenta difference

In general, there are differences between the simulation results for the models with lateral left and lateral right placentas despite the fact that the 'Expecting' model is symmetrical with respect to the sagittal plane. This is partly due to the application of the three-point seatbelt which is not symmetrical; in the right-hand-drive vehicles, the driver's shoulder belt runs from the right shoulder across the chest to the left hip bone. In addition, the multibody fetus in the uterus is also asymmetric, due to the crossing of legs, where the left leg of the fetus interacts differently with the uterus than the right leg of the fetus.

## 4. CONCLUSIONS

The results demonstrate that placental position has a significant effect on the strain levels at the UPI. The research also suggests that in all cases pregnant women with placenta located at the anterior position within the uterus has the highest risk of placental abruption amongst the placental location considered in this investigation. Placenta located at the fundal position, the most common placental location, has the second highest risk. Placenta located at the lateral positions has a lower risk of placental abruption when the seatbelt is worn. However, it is still important to wear the seatbelt as the risk appears to increase significantly when no seatbelt is worn. Posterior placenta always has the lowest placental abruption risk amongst the placental location considered in this investigation.

The results also demonstrate that the restraint systems play a significant role in providing protection to the pregnant occupant but their contributions vary considerably. The difference between the fully restraint (seatbelt and airbag) and the seatbelt only cases is very small. Being fully restrained appears to be the safest option however, three-point seatbelt seems to be the most effective restraint system in the protection of pregnant driver and her fetus even when it is used on its own. Hence, the seatbelt should always be worn as advised to protect the pregnant driver. The air-bag only and no restraint cases show very little difference, confirming that the airbag on its own contributes very little to protect the pregnant driver and her fetus.

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