INJURIES TO PREGNANT OCCUPANTS IN AUTOMOTIVE CRASHES

Kathleen DeSantis Klinich
Lawrence W. Schneider
Jamie L. Moore
University of Michigan Transportation Research Institute
Mark D. Pearlman
University of Michigan Health Systems
United States
Paper Number 98-SP-P-17

ABSTRACT

Injuries unique to pregnant occupants involved in motor-vehicle crashes include placental abruption, uterine rupture or laceration, and direct fetal injury. The mechanisms and characteristics of these injuries are discussed using examples from a literature review and from recent investigations of crashes involving pregnant occupants. In addition, a review of the relationship between the pregnant driver and automotive restraints and the steering wheel illustrates how injury potential may differ from the non-pregnant occupant.

AUTOMOTIVE TRAUMA IN PREGNANCY

Introduction

Firm statistics on fetal loss resulting from automotive trauma are not available because fetal death certificates do not record recent maternal involvement in crashes as a potential cause of death. In addition, since miscarriage occurs in 10-20% of all pregnancies in the early part of pregnancy, only deaths to fetuses over 20 weeks gestational age are legally defined and recorded. However, based on the frequencies of pregnancies and crash involvement of the general population, it has been estimated that between 1500 and 5000 fetal losses occur each year in the United States as a result of maternal involvement in automotive crashes (Pearlman 1997). Additional uncounted adverse fetal outcomes occur as well, as many children grow up disabled as a result of injuries sustained in utero. Even if a fetus survives, complications arising from early emergency delivery of a premature fetus (such as low birth weight and neonatal respiratory distress syndrome) can lead to long-term negative consequences for the child.

Pregnant Anatomy

Figure 1 illustrates the general anatomy of a pregnant abdomen (Pritchard et al. 1985). The uterus is a muscular organ that grows in capacity from 5 mL to 5 to 10 L over the course of pregnancy. Its wall thickness at seven months is about 2 cm, and at term (40 weeks) it is about 1 cm. The size of the uterus depends more on the size of the fetus than the size of the mother. Since most women generally have babies who weigh 2.7 to 3.6 kg (6 to 8 pounds), uterine size is not expected to vary significantly with the stature or weight of the mother. The uterus is attached at its base to the cervix which leads to the vagina, but is otherwise unattached in the abdominal cavity. As the uterus grows, it pushes the other abdominal organs rearward and upward. The base of the uterus is in close proximity to the lumbar spine.

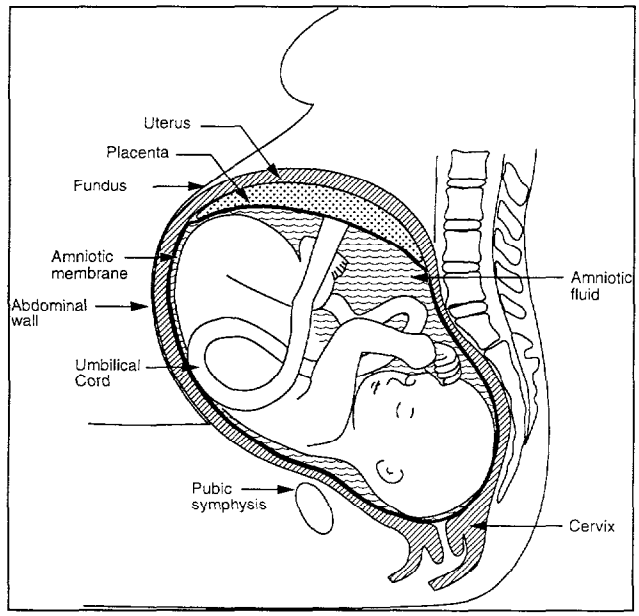

Figure 1. Pregnant anatomy

The placenta is a vascular organ within the uterus that exchanges oxygen, nutrients, and waste between the mother and fetus. Commonly called the "afterbirth," it separates from the uterus and delivers spontaneously after the fetus is born. Eighty percent of placentas are located near the top (fundus) of the uterus by the third trimester. It is roughly circular in shape, and measures 2 to 2.5 cm in thickness in the last trimester of pregnancy. It covers roughly one-fourth of the internal surface area of the uterus throughout pregnancy. The placenta attaches to the uterus by microvilli, which are finger-like projections (diameter of ~ 50 micrometers) that grow into the

superficial covering of the uterine wall (decidual layer). The interface between the uterus and placenta is considered to be weaker than either of the two tissues.

The amniotic membrane lines the inner surfaces of the uterus and placenta and contains the fetus and the amniotic fluid. The umbilical cord runs from the placenta through the wall of the membrane to the fetus. As the fetus grows, the relative proportion of the uterine volume filled with amniotic fluid decreases. By the last trimester, the fetus is positioned with its head down in over 95% of pregnancies.

Pregnant Occupants in the Automotive Environment

A research program targeted toward increasing understanding of automotive trauma in pregnancy and developing a second-generation pregnant abdomen for the small female crash dummy is currently underway. As part of this larger program, an anthropometric study of the pregnant automotive occupant is being conducted. Pregnant women in five different stature groups are being tested in laboratory simulations of vehicle interiors. Two seat heights are being used, one representing a mid-size sedan (H30=270 mm) and the other typical of a minivan or light truck (H30=360 mm). Belt anchorage locations are also varied. Subjects are measured in the 3rd, 5th, 7th, and 9th months of pregnancy to study how selected seat position, belt fit, and proximity to the steering wheel change with advancing pregnancy.

Data for fifteen subjects in four different stature groups are currently available. Table 1 shows the group number, mean stature at the initial test session, and number of subjects tested to date. Each subject was tested in four configurations at each visit: two at each seat height with different belt locations.

Table 1.
Subject Information

Group	Mean Stature (mm)	Number of Subjects
2	1580	3
3	1627	5
4	1664	2
5	1708	5

Abdomen-to-wheel clearance is the minimum distance between the bottom of the steering-wheel rim and the subject's midline abdomen contour. Figures 2 and 3 show the abdomen-to-wheel clearance averaged by subject group for each test session. Each point is the average of twice the number of subjects in each group, because each subject was tested twice at each seat height. Different belt conditions are not expected to affect abdomen-to-wheel clearance. Figure 2 illustrates the data for the mid-seat-height test configurations, while Figure 3 shows the data for the high-seat-height test conditions. As expected, all groups show decreasing abdomen-to-wheel clearance with increasing gestational age. The shortest subjects (Group 2) had the least clearance in each test session, while the tallest subjects (Group 5) had the most clearance. Groups 3 and 4 had similar levels of clearance in each test session. The tallest subjects (Group 5) show approximately 100 mm more clearance than the shortest subjects (Group 2) at each test session and at each seat height. Clearances are similar for the two different seat-height configurations.

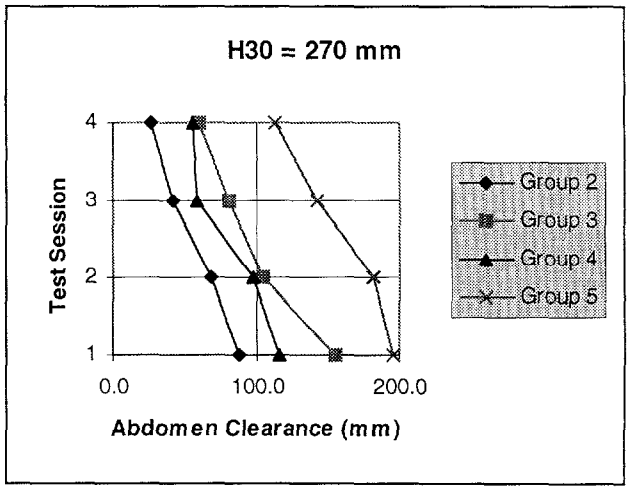

Figure 2. Abdomen-to-wheel-rim clearance averaged by subject group for each test session at mid-seat-height test conditions.

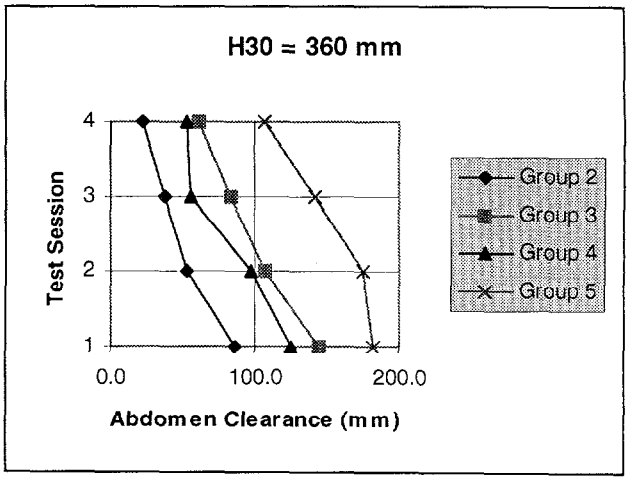

Figure 3. Abdomen-to-wheel-rim clearance averaged by subject group for each test session at high-seat - height test conditions.

Figure 4 shows a stick-figure representation of the average posture and anthropometry of Group-2 subjects

for each test session at mid-seat height conditions. The subjects did not move further away from the steering wheel as pregnancy progressed because of the need to comfortably operate the pedals.

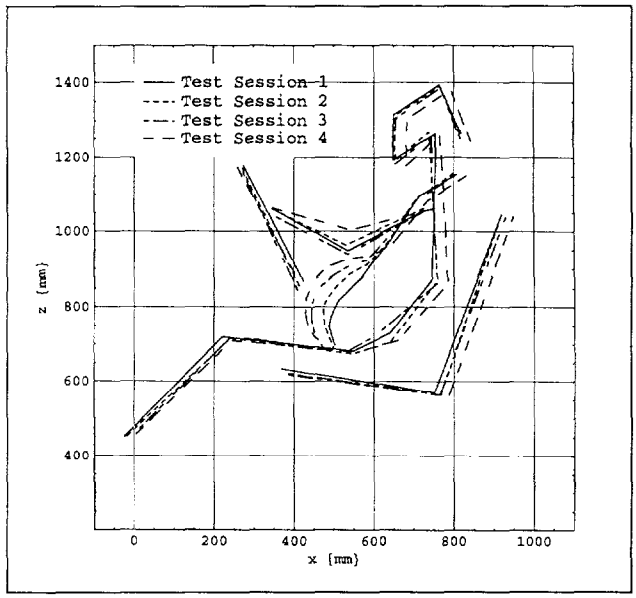

Figure 4. Average posture of Group-2 subjects for each test session at mid-seat-height conditions.

The position of the lap belt relative to the uterus was also measured during testing. Subjects were instructed to position the lap belt below the prominence of their pregnant abdomen, as recommended by the American College of Obstetricians and Gynecologists (ACOG 1991). Ideally, the top of the belt should be at or below the anterior superior iliac spines (ASIS), so the bony structures are loaded during impact rather than the soft tissues. Figure 5 shows a front view of the centerline of a lap belt for one subject. The geometric shape connects the fundus (top of uterus), left ASIS, pubic symphysis, and right ASIS. This subject, who was in her 37th week of pregnancy, positioned the belt so the centerline was very close to the ASIS points.

The side view of the lap belt relative to the pregnant abdomen in Figure 6 illustrates the challenges posed by pregnant anatomy to automotive safety engineers. This subject positioned the belt correctly, and it crossed very close to the left and right ASIS as desired. However, in the midline plane, the lap belt crosses over the protruding pregnant abdomen directly over the uterus. In a crash, the uterus would be loaded before the bony structures. For non-pregnant occupants, a correctly positioned lap belt loads the pelvis through the ASIS rather than the soft tissues of the abdomen.

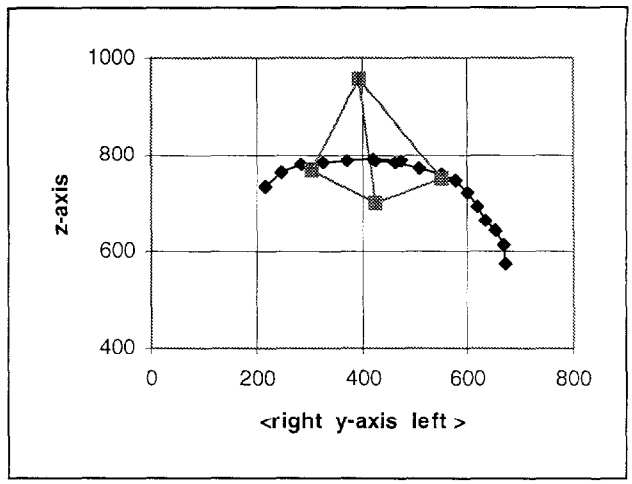

Figure 5. Front view of lap belt centerline (diamonds) relative to fundus, ASIS, and pubic symphysis (squares).

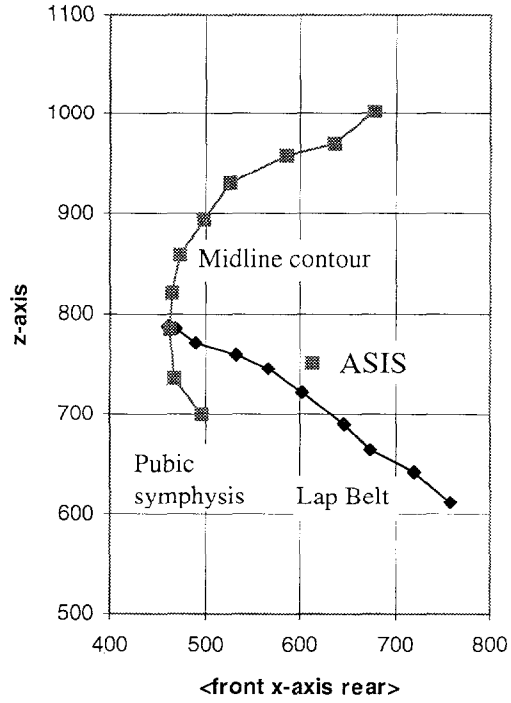

Figure 6. Side view of lap belt centerline (diamonds) showing its intersection with the midline contour (squares) of the pregnant abdomen.

INJURIES UNIQUE TO PREGNANT WOMEN IN CAR CRASHES

Overview

Table A.1 in the Appendix provides information on 120 automotive crashes involving pregnant occupants. Most of the cases (93) are taken from the medical and automotive safety literature. The main criteria for inclusion in this review was availability of information on restraint usage by the pregnant occupant and the pregnant occupant being at least 20 weeks pregnant. Since most medical case studies focus on the injuries and treatment and not the crash event, information regarding the impact direction is often unavailable. In addition, the estimate of the crash severity is usually not calculated and is derived from the occupant's or physicians' estimates. The cases from the literature are usually reported because they involve an unusual or serious injury and are not intended to be representative of situations experienced by most pregnant occupants.

The remaining 27 cases in Table A.1 are from UMTRI's ongoing accident investigation study of crashes involving pregnant occupants. Fourteen cases (designated GMP-0XX) are classified as major investigations, while 13 cases (designated GMP-2XX) are considered minor investigations. An investigation is usually considered minor if the vehicle or medical records are not available for inspection or review. However, even in these cases, the vehicle damage information is generally more complete than most of the cases reported in the medical literature. The UMTRI case set is expected to be more representative, as it includes a wider range of outcomes.

The first column in Table A.1 lists a case number for reference in this paper. The second column lists the occupant position in the vehicle, impact direction, and impact severity if the data are available. Some sources from the literature only reported the occupant as being a passenger and did not indicate whether the location was the front or rear seat. The type of crash is classified as front, side, rear, rollover, or multiple impact. Information on whether the crash was a "near" or "far"-side impact is usually not available. Crash severity is based on the following divisions: minor is less than 24 km/h (15 mph) change in velocity, moderate is 24 to 48 km/h (15 to 30 mph), and severe is greater than 48 km/h (30 mph). The values reported for major UMTRI cases are based on input of vehicle crush measurements into crash-reconstruction programs such as SMASH, and are therefore more accurate. The remaining crash-severity estimates were made by the occupants or physicians and probably relate more to the speed of travel before the crash rather than actual change in velocity. In the majority of cases in Table A.1, no estimate of crash severity is made.

The third column in Table A.1 lists the restraint conditions for the pregnant occupant. Some of the sources reported use of a belt restraint, but did not clarify whether a lap belt or 3-point belt was used, or if the belt was positioned properly; these cases are listed only as "restrained." If the pregnant occupant reported wearing the lap belt portion of the belt across the bulge of her pregnant abdomen (crossing near the umbilicus) rather than below it, belt use is documented as improper. The fourth column gives gestational age in weeks, with 40 weeks considered full term. In the text of this paper, gestational ages are grouped into four-week increments and referred to as the 5th month (20-23 weeks), 6th month (24-27 weeks), 7th month (28-31 weeks), 8th month (32-35 weeks), or 9th month (36 weeks or more) of pregnancy.

Maternal injuries are given in the fifth column and are described in two ways. The first term describes the overall severity of injuries that are not related to pregnancy. The categories are none, minor, moderate, and major. These descriptions are estimates of the maximum AIS scores (ignoring uterine or placenta injuries), with minor corresponding to MAIS 1 or 2, moderate, MAIS 3 or 4, and major, MAIS 5 or 6. The remainder of the maternal injury description describes the injuries to the uterus and placenta. Pelvic fractures are specifically noted in the maternal injury column as they are suspected to increase the probability of injury to the pregnant abdomen and fetus. Maternal death is indicated by italic type.

The sixth column describes the fetal outcome, specifically listing any direct injuries or complications. Fetal survival is indicated by italic type.

The final column lists the source of the case data. For cases from the literature, the source lists the authors and year of publication, plus a case number if the source presented more than one case. For UMTRI cases, the case number and year of the crash are given.

Figure 7 documents the distribution of crash types from Table A.1. The majority of crashes are frontal impacts (61%, n=74), followed by side impacts (25%, n=30). The breakdown of crash severity is shown in Figure 8, with over half of the cases not reporting any estimate of crash severity. The distribution of occupant position is shown in Figure 9, with most cases involving drivers (55%, n=66).

Figure 10 shows the distribution of restraint use of the pregnant occupants for the cases in Table A.1. About half (49%, n=59) were unrestrained. Only a few cases (3%, n=4) were confirmed to have improper belt use, with the lap belt positioned across, rather than under, the pregnant abdomen. Since the case dates range back to the 1960's, about 6% (n=7) used a lap belt only, often because it was all that was available. The gestational ages of the pregnant occupants appear in Figure 11, with most cases in the last trimester, particularly the last month.

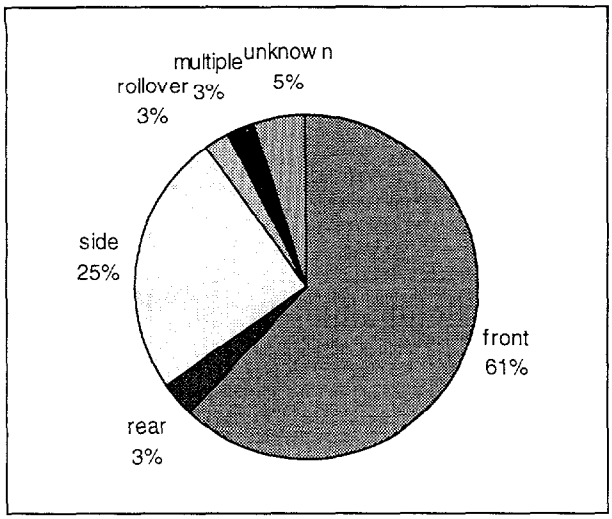

Figure 7. Distribution of impact type for cases in Table A.1.

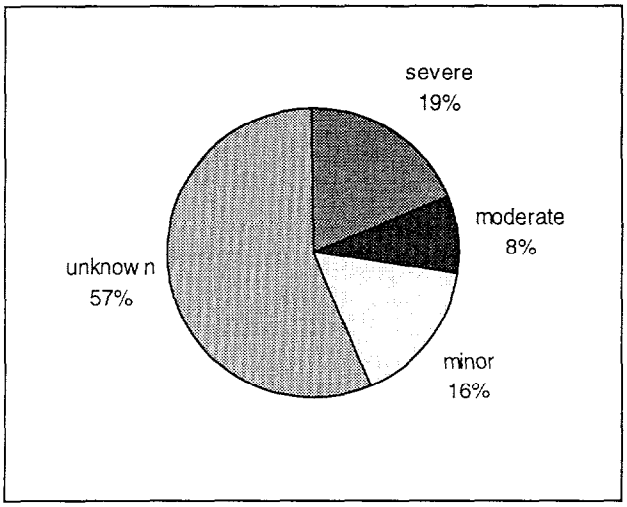

Figure 8. Distribution of estimated impact severity for cases in Table A.1.

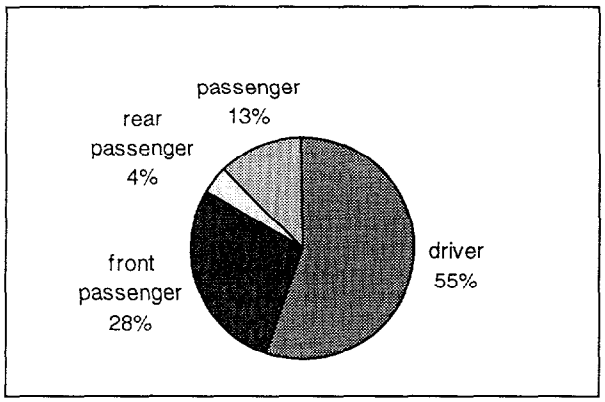

Figure 9. Distribution of seating position of pregnant occupant for cases in Table A.1.

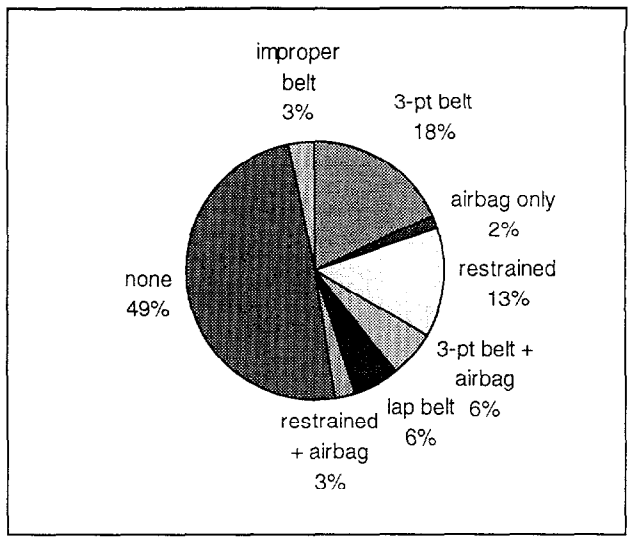

Figure 10. Distribution of restraint use by pregnant occupant for cases in Table A.1.

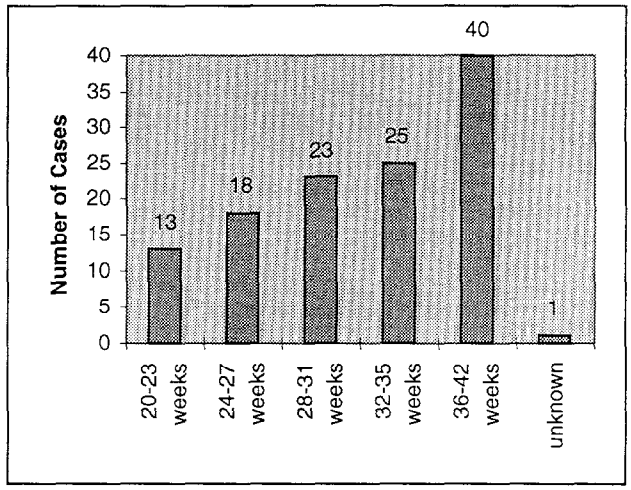

Figure 11. Distribution of gestational age for cases in Table A.1.

The chart in Figure 12 indicates the types of pregnancy-related injuries sustained by the pregnant occupants in Table A.1. The most frequent outcome is placenta injury only; none of the fetuses in these cases survived. There are six instances of placenta injury plus additional complications, with all of these fetuses surviving. Seventeen cases had placenta and direct fetal injuries. Eighteen cases had completely positive outcomes, although two of these mothers sustained pelvic fractures. Five cases involved only complications, and all of these fetuses survived. In eight cases, the fetus was stillborn and no direct injuries to the fetus or reproductive organs were found. However, five of these cases involved maternal death, so there are really just three stillborn cases

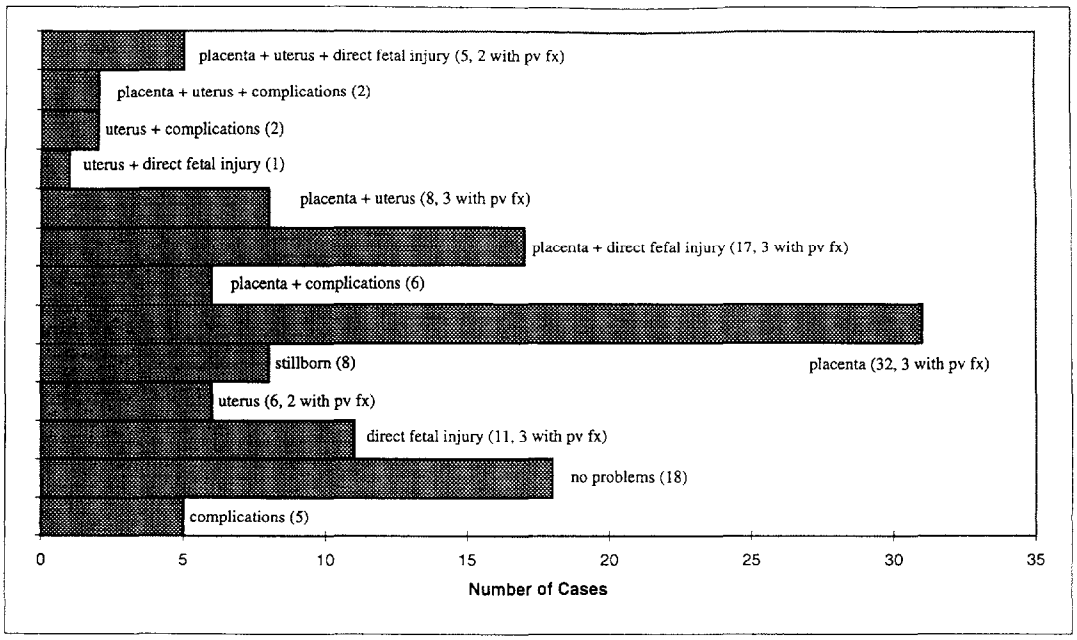

Figure 12. Distribution of injury patterns.

without additional explanation. Eight cases involve injuries to both the uterus and placenta. In one of these cases, the fetus survived although it experienced complications. Three other of these cases also involved pelvic fracture. The other most common injury patterns are direct fetal injury (11 cases, 3 with pelvic fracture), and uterine injury only (6 cases, two with pelvic fracture). In one of the uterine injury cases, the fetus survived with complications. The remaining bars show the less frequent combinations of placenta, uterine, direct fetal, and pelvic fracture injuries.

Of the 120 cases in Table A.1, nine involve both maternal and fetal death. While the mother survived in the other 111 cases, the fetus did not survive in 74 cases.

The remainder of this paper discusses each type of pregnancy injury and outcome in more detail, and highlights the characteristics of the crashes and injury patterns.

Placental Abruption

Placental abruption is the most common cause of fetal loss in automotive crashes. It occurs in 1 to 5% of minor severity crashes during pregnancy and from 20 to 50% of severe crashes during pregnancy. The injury occurs when the placenta detaches from the uterine wall, disrupting the supply of oxygen and nutrients to the fetus. Partial abruptions can also occur, with the possibility of the pregnancy continuing successfully depending on the degree of placental separation from the uterus. The interface between the placenta and the uterus is considered to be weaker than either the uterus or the placenta, and therefore usually fails before either the uterus or placenta fails.

Pearlman et al. (1990) have noted that the likelihood of placental abruption is independent of the placenta location on the uterus (Pearlman et al. 1990). This may imply that there are several mechanisms of placental abruption, with the particular cause depending on the placental location relative to the loading location and nature of the loading. For example, some placental abruptions may result from high-velocity, low-mass airbag loading, or from compression between the mother's body and the steering wheel, belt, or instrument panel. Abruption may also result from acceleration differentials between the placenta and uterus. Thus, mechanisms of placental abruption may include inertial loading, direct loading by the fetus, and excessive shear or tensile strain.

The first 69 cases in Table A.1 involve some injury to the placenta or the placenta/uterine interface. Of these cases, thirty-nine of the pregnant occupants were drivers, fourteen were front passengers, five were rear passengers, and eleven were passengers of unknown seating position. Most of the impacts were frontal (46), twelve were side, three were rollovers, two each were rear or multiple impacts, and four impact types were not reported. Many of the cases did not estimate impact severity (49), while

twelve were severe and four each were estimated to be minor or moderate impacts.

Forty-two cases (1-42) involve complete abruption and fifteen cases (43-57) involve partial abruptions. In eight cases (58-65), lacerations of the placenta occurred, and in the four remaining cases (66-69), the placenta was damaged but not separated or lacerated. Only two cases (16 and 33) resulted in both fetal and maternal death. When the mother survived, the fetus died in 56 cases. Twenty-two of the cases with placental injury also had direct fetal injury, fifteen cases also involve uterine laceration or rupture, and nine of these pregnant occupants sustained pelvic fractures.

In the majority of cases with placental abruption, the pregnant occupant was unrestrained (48 out of 69). One pregnant occupant sustaining a placental abruption was restrained by both a 3-point belt and a deploying airbag, eight were documented as properly using a 3-point belt, and twelve were listed as restrained without further specification. Five women used a lap belt only, and three wore the belt improperly with the lap belt portion positioned across the bulge of their abdomens. While these results show that placental injuries can occur to properly belted pregnant occupants, they also show that avoiding belt use during pregnancy may significantly increase the risk of placental abruption and subsequent fetal loss in a crash.

This compilation of case data also suggests that placental abruption may be more likely to occur later in the term of pregnancy. Five cases of placental injury involve women in their 5th month of pregnancy, 10 in the 6th, 13 in the 7th, 20 in the 8th, and 21 in the 9th month. The pregnant occupants were most likely to have a minor injury in addition to their placental injury (41 cases). Sixteen pregnant occupants sustained moderate injuries, two suffered major injuries, and ten sustained no injuries other that the placental injury. These findings agree with clinical experience in which women with serious pregnancy injuries often appear, at initial exam, to have sustained minor or no other injuries (Pearlman 1990).

Uterine Injury

Uterine rupture and lacerations are rare during pregnancy, occurring in less than 1% of pregnant trauma cases (Pearlman 1990). Injury to the uterus in automotive accidents occurs almost exclusively during pregnancy (compared to any other time) because it is much larger, extends outside the pelvic cavity, and is filled with fluid. While uterine rupture is very rare, the likelihood of fetal death with such an injury is near 100%.

Uterine injury is often reported in the literature as resulting from direct loading from the seat belt. While this may occur, it can also occur to unbelted women who are directly loaded by the steering wheel or instrument panel. Some cases report uterine damage directly beneath the area of seatbelt loading. For example, in case GMP-006 (Case 10), the pregnant driver sustained two lacerations approximately 50 mm apart extending across the lower uterus, corresponding to the width of the seat belt. Other cases (75 and 78) report the site of uterine rupture as being opposite the site of loading, suggesting a "contrecoup" type of injury mechanism.

Twenty-four cases in Table A.1 involve uterine injuries. In eleven of the cases, the pregnant occupant was the driver. Fourteen of the crashes were frontal impacts, seven were side, one was rear, one involved multiple impacts, and one involved unknown crash conditions. Of the seven side impacts, only one pregnant occupant may have been properly restrained (one had the lap belt improperly positioned and five were unrestrained). The impact severity is only estimated for five of the twenty-four uterine injury cases, so no conclusions can be drawn about the frequency of uterine injury and the severity of crashes.

Three different types of uterine injuries are reported: one complete transection (70), thirteen ruptures (1-8, 74-78) and ten lacerations (9-12, 43-44, 58, 71-73). All but three of these experienced fetal loss, and all three of these cases (10, 44, 71) involved fetal complications. Seven of the laceration cases and eight of the rupture cases involved at least a partial placental abruption. Seven of the uterine injury cases also involved direct fetal injury, and six uterine injuries were accompanied by pelvic fractures. (The proportion of cases with uterine injury in Table A.1 is higher than seen clinically, because the literature cases are more likely to report unusual injuries.)

In the twenty-four cases with uterine injury, only four of the pregnant occupants were properly restrained by a three-point belt, and one driver was also restrained by an airbag. Two additional cases reported restraint use, but did not report the type of belt or whether it was positioned properly. Half of the occupants with uterine injury were unbelted. For all the cases in Table A.1, the four cases where improper belt use was confirmed (lap belt portion placed across the dome of the abdomen) all resulted in uterine injury. In the last two cases with uterine injury, the occupants used only a lap belt.

Distribution of gestational ages of pregnant women with uterine injury is fairly uniform, with five occupants each in the 5th, 6th, and 8th months, six in the 7th month, and three in the 9th month. None of the pregnant occupants with uterine injury sustained major injuries, six sustained other moderate injuries, seventeen suffered other minor injuries, and one received no other injuries. This distribution of maternal injuries confirms the trend noted in the literature that pregnant women often sustain a uterine injury that is usually life-threatening to the fetus, while sustaining only minor injuries to themselves.

Direct Fetal Injury

Direct fetal injury (DFI) is also quite rare, occurring in less than 10% of automotive crashes involving pregnant occupants (Pearlman 1990). In the first three months of pregnancy, the uterus is still completely surrounded by the pelvis and is considered an abdominal organ. After the first three months, the uterus protrudes out from the abdomen, but the structure of the pregnant abdomen protects the fetus by encasing it in amniotic fluid which acts as a shock absorber to isolate the fetus. The fetus sometimes sustains injury from direct loading of the abdomen when the protective cavity is compromised by pelvic fractures or uterine rupture. The most frequently injured fetal body region is the head, because it is the largest part of the fetal body and offers the "biggest target." It is thought that skull fracture most often occurs when the fetal head is loaded against the bony structures of the maternal pelvis or spine by a belt, steering wheel, or instrument panel.

Judging from the thirty-four cases involving direct fetal injury in Table A.1, it appears that crashes with minor, moderate, or severe impact severities can all result in direct fetal injuries, although data on the crash severity are limited. Nineteen of the cases involved drivers as the maternal occupant. Nineteen were frontal impacts, ten were side, two were rear, and the remaining three were multiple or unknown types of impacts.

The cases with direct fetal injury in Table A.1 are numbers 1-3, 9, 13-16, 43, 45-53, 65-68, 70, and 79-90. As mentioned previously, the cases taken from the literature tend to focus on more unusual injuries, so the proportion of cases with direct fetal injury in Table A.1 is greater than that seen clinically. Twenty-two cases involve head injuries only, four involve both the head and thorax injuries, six involve thorax/abdomen injury only, and one injury each is documented for the spine and upper extremity. Of the sixteen cases in Table A.1 in which the mother sustained a pelvic fracture, eight of the fetuses sustained direct injuries to the head. Twenty-two of the direct fetal injury cases also involved placenta injuries, suggesting that accident conditions severe enough to result in direct fetal injury often result in placental damage as well. Six occupants sustained uterine injuries with direct fetal injury. Five fetuses with direct injuries survived, with three requiring emergency cesarean section (c/s) deliveries.

Most of the occupants with direct injuries to the fetus were not properly restrained. Nineteen were unbelted, four used a lap belt only, and three had the lap belt improperly positioned across the bulge of the abdomen. Five occupants were wearing the 3-point belt properly, and the remaining three occupants were reported to be using belt restraints, although the type of belt and placement are not reported.

The frequency of direct fetal injury for this sample is slightly skewed toward later gestational ages. Only two DFI cases occurred in the 5^{th} month, six occurred in the 6^{th} month, eight each in the 7^{th} and 8^{th} months, and ten in the 9^{th} month. Intuitively this makes sense, as the fetus is a bigger target as gestational age increases, and the amniotic fluid takes up a relatively smaller proportion of the uterus volume as pregnancy progresses. Direct fetal injuries occur regardless of the injury severity sustained by the mother, with eight of these cases having no maternal injury, sixteen having minor maternal injuries, eight having moderate injuries, and two having major injuries.

Other Negative Outcomes

Some pregnant automotive crash victims suffer negative pregnancy complications whether or not they sustain any placenta, uterus, or direct fetal injuries. One common occurrence is a premature delivery, in which the infant often has a low birth weight and can suffer from neonatal respiratory distress syndrome because its lungs are not fully developed. Both of these factors can lead to health problems and disabilities throughout the child's life.

Even if a fetus is very close to full term, maternal involvement in a crash can lead to an emergency cesarean delivery, which poses higher risks to the mother and neonate. Contractions often begin after an accident, sometimes requiring drug intervention to prevent early delivery. Crashes involving pregnant occupants occasionally result in stillborn births without any visible injury responsible for the loss.

In the sixteen negative outcome cases, nine of the pregnant occupants were drivers. Nine crashes were frontal impacts, two were side, three were rear, and two were unknown. Seven of these crashes were rated as severe, one as moderate, and three as minor in crash severity, with no crash-severity rating available for the remaining five cases.

Table A.1 contains seven cases (90-93, 97, 99,100) in which the crash resulted in a negative pregnancy outcome without any placenta, uterus, or direct fetal injuries. There are also nine cases with placenta or uterine injury (10, 17-19, 44, 54-56, 71) where the fetus survived but experienced some of the additional negative outcomes described above. In three cases, the fetus was stillborn after the crash, although there were no placenta, uterus, or fetal injuries responsible for the loss. In three other cases, the pregnant occupant started having contractions after the crash although no intervention was needed. In one of these cases, the neonate was born months after the crash and diagnosed with brain damage attributed to the crash. In the remaining case, the neonate suffered from hydrocephalus that may have resulted from the crash at 28 weeks gestation. The nine cases with placenta or uterine

damage required emergency cesarean delivery of premature infants. Five of these infants suffered from seizures or newborn respiratory distress syndrome.

In these sixteen negative outcome cases, eleven mothers were not using belt restraints. Two used a 3-point belt and airbag, one used a 3-point belt only, and in one case with an unspecified type of belt restraint, the airbag deployed. One pregnant occupant used only a lap belt.

The gestational ages of the cases with negative outcomes is almost evenly distributed over the last three months of pregnancy, with 5 each in the 7th, 8th, and 9th months and one case in the 6th month. Four of the mothers sustained no other injuries, ten had minor injuries only, and two had moderate levels of injury.

Positive Outcomes

Eighteen of the cases in the Table A.1 (103-120) had good fetal outcomes with no complications. The majority of these cases are from the UMTRI study, as the medical literature usually reports only complicated cases. All of the mothers and fetuses in these cases survived.

Twelve of the pregnant occupants were drivers, while the remaining six were front-seat passengers. Ten impacts were frontal, six were side, one was a rear impact, and one impact type was not recorded. Crash severity is available for all of these cases, with thirteen being minor, four moderate, and one severe.

The most obvious difference between the positive-outcome cases and the other cases in Table A.1 is the restraint usage of the maternal occupant: 17 out of 18 of the occupants in the positive outcome cases used a restraint. Seven of these used a 3-point belt, seven used a 3-point belt and the airbag deployed, and two were unbelted but the airbag deployed.

These cases are weighted towards the last month of pregnancy, with ten cases in the 9th month of pregnancy, three in the 5th month, two in the 8th month, and one each in the 6th, 7th, and unknown months. Twelve of the mothers sustained minor injuries, three had none, and three suffered moderate injuries. Two of the mothers had pelvic fractures.

DISCUSSSION

The preceding descriptions of injuries sustained by pregnant women in crashes highlights the conditions under which different injuries occur. To provide an overview, histograms of the distributions of the independent variables impact type, impact severity, seating position, restraint use, and gestational age were developed for all cases in Table A.1, and for subsets of the cases based on injury type or outcome. The different proportions in each distribution were grouped according to the different levels of each independent variable for plotting in Figures 13 through 17. The number of cases in each injury or outcome appears in Table 2. The sum of the numbers of cases in all the different groups does not equal the total number of cases in Table A.1 because cases with more than one injury are included more than once (i.e., a case with both uterus and placenta injuries is counted in both categories).

Table 2.
Number of Cases in Each Outcome

Outcome	Number of Cases
All Cases	120
Placenta	69
Uterus	24
Direct Fetal	34
Negative Outcomes	16
Positive Outcomes	18

The distributions of impact type in Figure 13 show that, in general, the distributions for each outcome are similar to the overall distribution. The negative outcome cases had higher proportions of rear and unknown impacts. The cases with placenta injuries had a slightly lower proportion of side impacts and a slightly higher proportion of front impacts.

Figure 14 shows distributions of estimated impact severity. The negative outcome cases had higher proportions of major and minor impacts and had fewer unknown crash severities. The positive outcome cases had the highest proportions of minor and moderate severity crashes, and had no unknown impact severities.

The distributions of pregnant occupant seating position are found in Figure 15. Most of the outcomes have a seating-position distribution similar to the overall distribution. The uterine injuries have the highest proportion of front passengers and the lowest proportion of drivers. The placenta injury cases have the lowest proportion of front passengers and the highest proportion of rear passengers.

Figure 16 illustrates the distributions of restraint use by pregnant occupants. Cases with positive outcomes have the highest percentage of 3-point belt use and 3-point belt plus airbag use, and the lowest percentage of no restraint use. Placenta injuries and negative outcomes have relatively high proportions of not using restraints. Uterine injuries have the highest proportion of improper belt use.

The distribution of gestational age for the different outcomes is found in Figure 17. The positive outcome cases had the highest proportion of cases in the 9th month of pregnancy. Since a birth resulting from a crash would not be considered premature in the ninth month, this may contribute to this shift in proportion. Uterus injury cases

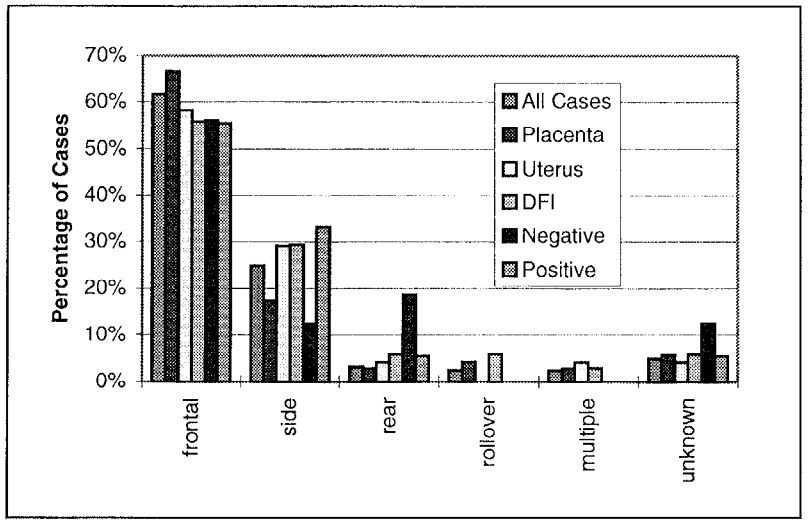

Figure 13. Distributions of impact type for all cases in Table A.1 and by injury or outcome, grouped by impact type.

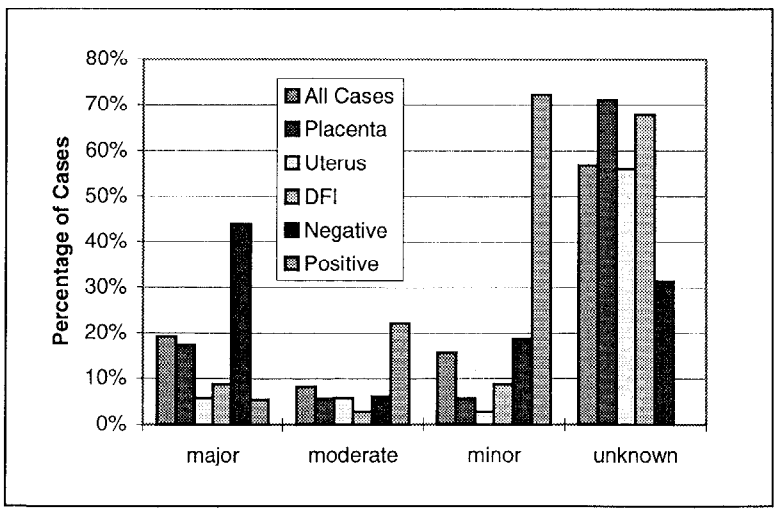

Figure 14. Distributions of impact severity for all cases in Table A.1 and by injury or outcome, grouped by impact severity.

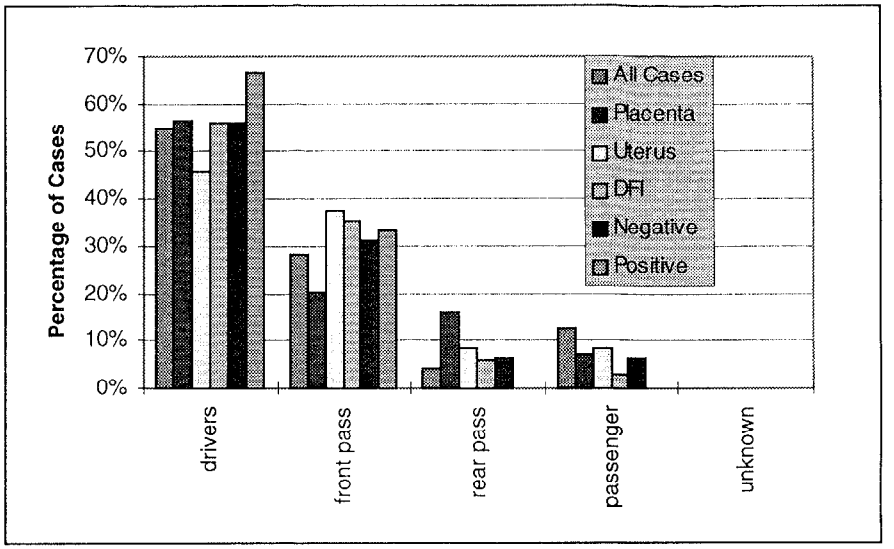

Figure 15. Distributions of pregnant occupant seating position for all cases in Table A.1 and by injury or outcome, grouped by seating position.

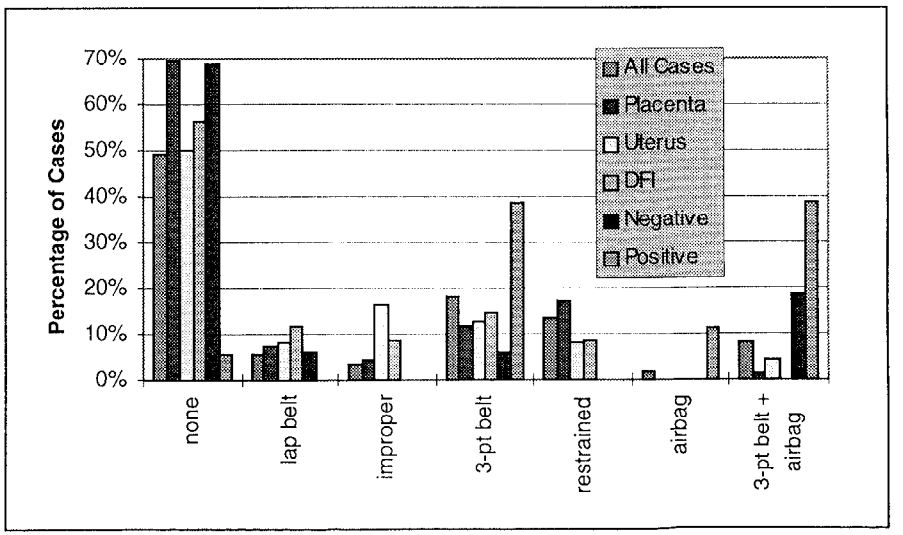

Figure 16. Distributions of pregnant occupant restraint use for all cases in Table A.1 and by injury or outcome, grouped by restraint use.

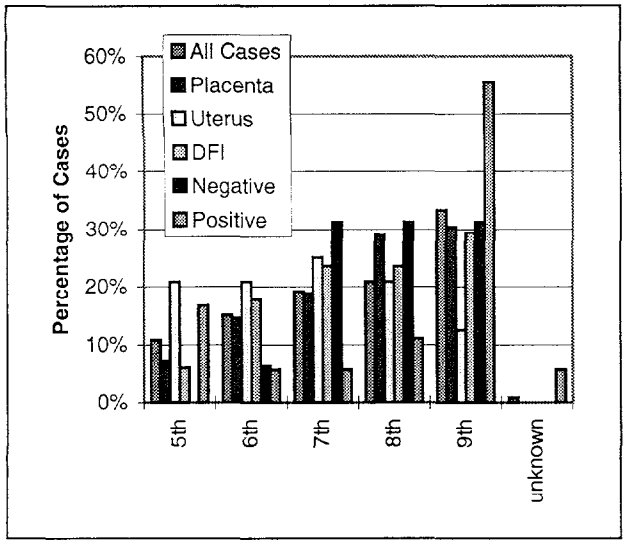

Figure 17. Distributions of gestational age for all cases in Table A.1 and by injury or outcome, grouped by gestational age.

were the most evenly distributed, and had the highest proportions in the 5th and 6th months of pregnancy. The proportion of placenta injuries seems to increase with gestational age, as do direct fetal injuries. Negative outcomes primarily occur in the last trimester of pregnancy.

CONCLUSIONS

A review of injuries specific to pregnant motor vehicle occupants illustrates the following points regarding pregnant occupants involved in automotive crashes.

- All nine cases involving maternal death resulted in fetal death, and eight of these women were unbelted. Thus, the most basic way to protect the fetus is to protect the mother through proper use of belt restraints.
- While placental, uterine, and fetal injuries may occur with properly belted occupants, the majority of the cases involving these injuries are to unrestrained occupants.
- The distinguishing characteristic of the cases with completely positive fetal outcomes was proper restraint use by the mother.
- 65% of the cases with direct fetal injury also involved placental injury, as did 63% of the cases with uterine injury. Thus, reducing the likelihood of placental abruption is likely to reduce the probability of uterine and direct fetal injury as well.
- All pregnant women involved in crashes, even minor ones, should immediately seek medical attention. In most cases with fetal loss, the mother sustained only minor or no other injuries other than placental, uterine, or fetal damage.
- The anatomy of pregnant women while seated in automotive posture poses a unique challenge to restraint designers because of difficulty positioning the lap belt and close proximity to the steering wheel and airbag module.

The information presented in this paper will be used to guide the development of the second-generation pregnant crash dummy. A key goal of the next-generation design is to assess the likelihood of placental abruption, the leading cause of fetal death in crashes.

ACKNOWLEDGMENTS

The work covered by this report was financed by GM pursuant to an agreement between GM and the U.S. Department of Transportation. The authors gratefully appreciate their support.

REFERENCES

ACOG Technical Bulletin #161 (1993). Trauma During Pregnancy, *International Journal of Gynecology and Obstetrics*, 40:165-170.

Agran, P. F., Dunkle, D. E., Winn, D. G., Kent, D. (1986). Fetal Death in Motor Vehicle Collisions. *30th Annual AAAM Proceedings*, 285-294.

Astarita, D. C., Feldman, B. (1997). Seat Belt Placement Resulting in Uterine Rupture. *Journal of Trauma*, 42(4):738-740.

Bowdler, N., Faix, R. G., Elkins, T. (1987). Fetal Skull Fracture and Brain Injury After a Maternal Automobile Accident: A Case Report. *Journal of Reproductive Medicine*, 32(5):375-378.

Chetcuti, P., Levene, M. I. (1987). Seat Belts: A Potential Hazard to the Fetus. *Journal of Perinatal Medicine*, 15(2):207-209.

Civil, I. D., Talucci, R. C., Schwab, C. W. (1988). Placental Laceration and Fetal Death as a Result of Blunt Abdominal Trauma. *Journal of Trauma*, 28(5):708-710.

Connor, E., Curran, J. (1976). In Utero Traumatic Intra-Abdominal Deceleration Injury to the Fetus--A Case Report. *American Journal of Obstetrics and Gynecology*, 125(4):567-569.

Cumming, D. C., Wren, F. D. (1978). Fetal Skull Fracture From an Apparently Trivial Motor Vehicle Accident. *American Journal of Obstetrics and Gynecology*, 132(3):342-343.

Dash, N., Lupetin, A. R. (1991). Uterine Rupture Secondary to Trauma: CT Findings. *Journal of Computer Assisted Tomography*, 15(2):329-331.

Dittrich, K. C. (1996). Rupture of the Gravid Uterus Secondary to Motor Vehicle Trauma. *Journal of Emergency Medicine,* 14(2):177-180.

Evard, J. R., Sturner, W. Q., Murray, E. J. (1989). Fetal Skull Fracture from an Automobile Accident. *American Journal of Forensic Medicine and Pathology*, 10(3):232-234.

Fakhoury, G. W., Gibson, J. R. M. (1986). Seat Belt Hazards in Pregnancy: Case Report. *British Journal of Obstetrics and Gynaecology*, 93(4):395-396.

Ford, R. M., Picker, R. H. (1989). Fetal Head Injury Following Motor Vehicle Accident; An Unusual Case of Intrauterine Death. *Australian and New Zealand Journal of Obstetrics and Gynecology*, 29(1):72-73.

Fries, M. H., Hankins, G. D.V. (1989). Motor Vehicle Accident Associated with Minimal Maternal Trauma but Subsequent Fetal Demise. *Annals of Emergency Medicine*, 18(3):301-304.

Galle, P. C., Anderson, S. G. (1979). A Case of Automobile Trauma During Pregnancy. *Obstetrics and Gynecology*, 54(4):467-468.

Griffiths, M., Hillman, G., Userwood, M. (1991). Seat Belt Injury in Pregnancy Resulting in Fetal Death. A Need for Education? Case Reports. *British Journal of Obstetrics and Gynaecology,* 98(3):320-321.

Handel, C. K. (1978). Case Report of Uterine Rupture After an Automobile Accident. *Journal of Reproductive Medicine*, 20(2):90-92.

Harrison, S. D., Nghiem, H. V., Shy, K. (1995). Uterine Rupture with Fetal Death Following Blunt Trauma. *American Journal of Roentgenology,* 165(6):1452.

Hartl, R., Ko, K. (1996). In Utero Skull Fracture: Case Report. *Journal of Trauma,* 41(3):549-552.

Heitzman, E. R., Markarian, B. (1970). Vaginal Bleeding After Trauma in Pregnant Woman. *New York State Journal of Medicine*, 70(18):2338-2340.

Kettel, L. M., Branch, D. W., Scott, J. R. (1988). Occult Placental Abruption After Maternal Trauma. *Obstetrics and Gynecology*, 71(3 pt 2):449-453.

Knuppel, R. A., Salvatore, D. L., Agarwal, R., et al. (1994). Documented Fetal Brain Damage Resulting From a Motor Vehicle Accident. *Journal of Ultrasound in Medicine,* 13(5):402-404.

Landers, D. F., Newland, M., Penney, L. L. (1989). Multiple Uterine Rupture and Crushing Injury of the Fetal Skull After Blunt Maternal Trauma: A Case Report. *Journal of Reproductive Medicine*, 34(12):988-993.

Lavin, J. P., Miodovnik, M. (1981). Delayed Abruption After Maternal Trauma as a Result of an Automobile Accident. *Journal of Reproductive Medicine*, 26(12):621-624.

Levin, R. D., Edson, M. (1994). A Pregnant Pause: Blunt Urologic Trauma in a Young Woman. *Urology*, 44(5):764-767.

Matthews, C. D. (1975). Incorrectly Used Seat Belt Associated with Uterine Rupture Following Vehicular Collision. *American Journal of Obstetrics and Gynecology*, 121(8):1115-1116.

Matthews, G., Hammersley, B. (1997). A Case of Maternal Pelvic Trauma Following a Road Traffic Accident, Associated with Fetal Intracranial Haemorrhage. *Journal of Accident and Emergency Medicine*, 14(2):115-7.

McCormick, D.R. (1968). Seat Belt Injury: Case of Complete Transection of Pregnant Uterus. *Journal of the American Osteopathic Association*, 67(10):1139-1141.

Nichols, M. M., Weedn, V. W. (1986). Placental Laceration and Stillbirth Following Motor Vehicle Accident: with Legal Ramifications. *Texas Medicine*, 82(3):26-28.

Parkinson, E. B. (1964). Perinatal Loss Due to External Trauma To The Uterus. *American Journal of Obstetrics and Gynecology*, 90(1):30-33.

Pearlman, M. D., (1997). Motor Vehicle Crashes, Pregnancy Loss, and Preterm Labor, *International Journal of Gynaecology and Obstetrics*, 57(2):127-132.

Pearlman, M. D., Tintinalli, J. E., Lorenz, R. P. (1990). Blunt Trauma During Pregnancy. *New England Journal of Medicine,* 323(23):1609-1613.

Pearlman, M. D., Tintinalli, J. E., Lorenz, R. P, et al., (1988). Trauma in Pregnancy. *Annals of Emergency Medicine*, 17(8):829-834.

Pepperell, R. J., Rubinstein, E., MacIsaac, I. A. (1977). Motor-Car Accidents During Pregnancy. *Medical Journal of Australia*, 1(7):203-205.

Poulson, Jr., A. M., Gabert, H. A. (1973). Fetal Death Secondary to Nonpenetrating Trauma to the Gravid Uterus. *American Journal of Obstetrics and Gynecology,* 116(4):580-582.

Pritchard, J. A., MacDonald, P. C., Gant, N. F. (1985). *Williams Obstetrics*, Seventeenth Edition. Appleton-Cnetruy-Crofts, Norwalk.

Punnonen, R. (1974). Traumatic Premature Separation of Placenta. *Annales Chirurgiae et Gynaecologiae Fenniae*, 63(6):487-488.

Raney, E. H. (1970). Fetal Death Secondary to Non-Penetrating Trauma to the Gravid Uterus.

American Journal of Obstetrics and Gynecology, 106(2):313-314.

Ravangard, F., Porter, C. V. (1980). Traumatic Laceration of the Placenta. *West Virginia Medical Journal*, 76(6):125-129.

Rothenberger, D. A., Horringan, T. P., Sturm, J. T. (1981). Neonatal Death Following In Utero Traumatic Splenic Rupture. *Journal of Pediatric Surgery*, 16(5):754-755.

Rowe, T. F., Lafayette, S., Cox, S. (1996). An Unusual Fetal Complication of Traumatic Uterine Rupture. *Journal of Emergency Medicine*, 14(2):173-176.

Rubovits, F. E. (1964). Traumatic Rupture of the Pregnant Uterus From "Seat Belt" Injury. *American Journal of Obstetrics and Gynecology*, 90(6):828-829.

Sherer, D. M., Abramowicz, J. S., Babkowski, R., et al. (1993). Extensive Fetal Intrathoracic Injuries Sustained in a Motor Vehicle Accident. *American Journal of Perinatology*, 10(10):414-416.

Siddal-Allum, J. N., Hughes, J. H., Kaler, S., Reginald, P. W. (1991). Splenic Rupture in Utero Following a Road Traffic Accident: Case Report. *British Journal of Obstetrics and Gynaecology*, 98(3):318-319.

Sims, C. J., Boardman, C. H., Fuller, S. J. (1996). Airbag Deployment Following a Motor Vehicle Accident in Pregnancy. *Obstetrics and Gynecology*, 88(4 pt 2):726.

Smith, A. J., LeMire III, W. A., Hurd, W. W., and Pearlman, M. (1994). Repair of the Traumatically Ruptured Gravid Uterus. *Journal of Reproductive Medicine*, 39(10):825-828.

Stafford, P. A., Biddinger, P. W., Zumwalt, R. E. (1988). Lethal Intrauterine Fetal Trauma. *Obstetrics and Gynecology*, 159(2):485-589.

Stuart, G. C. E., Harding P. G. R., Davies, E. M. (1980). Blunt Abdominal Trauma in Pregnancy. *Canadian Medical Association Journal*, 122(8):901-905.

Svendsen, E., Morild, I. (1988). Fetal Strangulation Following Uterine Rupture. *American Journal of Forensic Medicine and Pathology*, 9(1):54-57.

Van Enk, A., Van Zwam, W. (1994). Uterine Rupture: A Seat Belt Hazard. *Acta Obstetricia et Gynecologica Scandinavcia*, 73(5):432-433.

Weinstein, E. C., Pallais, V. (1968). Rupture of the Pregnant Uterus From Blunt Trauma. *Journal of Trauma*, 8(6):1111-1112.

Whitehouse, D. B. (1972). Hazard to Fetus from Safety Harness. *British Medical Journal*, 1(798):510.

APPENDIX A

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
1	driver side impact	improper 3-pt belt	28	minor, placental abruption, uterine rupture	brain hemorrhages	Handel (1978)
2	driver front impact	none	34	moderate, pelvic fx, placental abruption, uterine rupture	skull fracture	Landers et al. (1989)
3	front passenger front impact	lap belt	22	minor, placental abruption, uterine rupture	decapitation	Rowe et al. (1996)
4	passenger side impact	none	37	minor, placental abruption, uterine rupture	stillborn	Pepperell et al. Case 13 (1977)
5	driver front impact moderate crash	none	34	minor, placental abruption, uterine rupture	stillborn	Agran et al. Case 6 (1986)
6	driver side impact	none	24	minor, pelvic fx, placental abruption, uterine rupture	stillborn	Dash & Leptin (1991)
7	rear passenger front impact severe crash	none	30	moderate, pelvic fx, placental abruption, uterine rupture	stillborn	Dittrich (1996)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
8	driver front impact moderate crash	3-pt belt	22	minor, placental abruption, uterine rupture	stillborn	Harrison et al. (1996)
9	rear passenger	improper lap belt	27	minor, placental abruption, uterine laceration	brain hemorrhage, transected aorta & spine, lacerated liver & kidney	Astarita & Feldman (1997)
10	driver front impact minor crash	3-pt belt + airbag	35	minor, placental abruption, uterine laceration	*premature birth, respiratory distress*	UMTRI GMP-006 (1997)
11	front passenger front crash	improper 3-pt belt	25	minor, placental abruption, uterine laceration	stillborn	Matthews (1975)
12	front passenger front crash	none	32	moderate, placental abruption, uterine laceration	stillborn	Smith et al. Case 1 (1994)
13	driver side impact	restrained	26	minor, placental abruption	skull fracture	Pepperell et al. Case 6 (1977)
14	passenger rollover	restrained	28	minor, placental abruption	rib fracture, liver rupture	Pepperell et al. Case 19 (1977)
15	driver front impact	none	35	moderate, placental abruption & laceration	skull fracture	Agran et al. Case 7 (1986)
16	driver front impact	none	34	*major, placental abruption*	skull fracture	Pepperell et al. Case 24 (1977)
17	driver front impact severe crash	none	28	minor, placental abruption	*emergency C/S, premature, respiratory distress*	Lavin and Miodovnik (1981)
18	rear passenger rear impact severe crash	none	34	minor, placental abruption	*premature*	UMTRI GMP-207A (1996)
19	front passenger rear impact severe crash	none	32	minor, placental abruption	*premature, possible head injury*	UMTRI GMP-207B (1996)
20	driver front impact severe crash	3-pt belt	34	minor, placental abruption	stillborn	Whitehouse (1974)
21	driver front impact	restrained	37	minor, placental abruption	stillborn	Pepperell et al. Case 4 (1977)
22	driver front impact	restrained	27	minor, placental abruption	stillborn	Pepperell et al. Case 5 (1977)
23	driver side impact	restrained	28	none, placental abruption	stillborn	Pepperell et al. Case 7 (1977)
24	driver side impact	restrained	29	minor, placental abruption	stillborn	Pepperell et al. Case 8 (1977)
25	passenger front impact	none	36	minor, placental abruption	stillborn	Pepperell et al. Case 10 (1977)
26	passenger front impact	none	26	moderate, placental abruption	stillborn	Pepperell et al. Case 11 (1977)
27	passenger front impact	restrained	32	none, placental abruption	stillborn	Pepperell et al. Case 15 (1977)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
28	passenger side impact	restrained	36	moderate, placental abruption	stillborn	Pepperell et al. Case 16 (1977)
29	passenger side impact	restrained	30	minor, placental abruption	stillborn	Pepperell et al. Case 17 (1977)
30	passenger front impact	restrained	34	minor, placental abruption	stillborn	Pepperell et al. Case 18 (1977)
31	passenger front impact	restrained	34	minor, placental abruption	stillborn	Pepperell et al. Case 20 (1977)
32	passenger front impact	restrained	37	minor, placental abruption	stillborn	Pepperell et al. Case 21 (1977)
33	passenger side impact	none	34	*major, pelvic fx, placental abruption*	stillborn	Pepperell et al. Case 25 (1977)
34	rear passenger rollover severe crash	none	23	moderate, placental abruption	stillborn	Agran et al. Case 2 (1986)
35	driver front impact moderate crash	none	23	minor, placental abruption	stillborn	Agran et al. Case 3 (1986)
36	driver front impact severe crash	none	26	minor, placental abruption	stillborn	Agran et al. Case 4 (1986)
37	driver front impact	none	30	minor, placental abruption	stillborn	Agran et al. Case 5 (1986)
38	driver front impact moderate crash	none	38	minor, placental abruption	stillborn	Agran et al. Case 8 (1986)
39	driver front impact	none	39	minor, placental abruption	stillborn	Agran et al. Case 9 (1986)
40	driver multiple impact	3-pt belt	32	moderate, pelvic fx, placental abruption	stillborn	Pearlman et al. (1988)
41	driver front impact severe crash	3-pt belt	40	moderate, placental abruption	stillborn	UMTRI GMP-101 (1997)
42	driver front impact	3-pt belt	24	none, placental abruption	stillborn	UMTRI GMP-208 (1994)
43	front passenger side impact	none	31	minor, pelvic fx, partial placental abruption, uterine laceration	skull fracture, scalp laceration	Poulson & Gabert (1973)
44	driver front impact	none	29	moderate, partial placental abruption, uterine laceration	*emergency C/S, premature*	Kettel et al. Case 2 (1988)
45	front passenger front impact	lap belt	28	minor, partial placental abruption	brain hemorrhages	Raney (1970)
46	front passenger side impact	none	37	moderate, pelvic fx, partial placental abruption	*emergency C/S, skull fracture, brain hemorrhages, apnea*	Bowdler et al. (1987)
47	front passenger front impact	none	33	minor, partial placental abruption	brain hemorrhages	Stafford et al. Case 4 (1988)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
48	front passenger multiple impact	3-pt belt	34	none, pelvic fx, partial placental abruption	skull fracture, brain contusions and lacerations	Stafford et al. Case 5 (1988)
49	driver front impact	none	27	minor, partial placental abruption	brain hemorrhages	Stafford et al. Case 8 (1988)
50	rear passenger rollover	none	41	minor, partial placental abruption	*emergency C/S, skull fracture*	Hartl and Ko (1996)
51	driver front	none	36	none, partial placental abruption	chest hemorrhages	Stafford et al. Case 2 (1988)
52	driver front impact minor crash	none	39	none, partial placental abruption	lacerated spleen	Rothenberger et al. (1981)
53	driver front impact	none	39	moderate, partial placental abruption	liver, adrenal, and kidney contusions, seizures	Connor & Curran (1976)
54	driver front impact minor crash	none	36	none, partial placental abruption	*emergency C/S, premature*	Punnonan (1974)
55	front passenger front impact severe crash	lap belt	37	none, partial placental abruption	*emergency C/S, seizures, renal failure*	Chetcuti and Levene (1987)
56	front passenger	none	34	none, partial placental abruption	*emergency C/S, premature*	Kettel et al. Case 3 (1988)
57	driver front impact	none	41	minor, partial placental abruption	stillborn	Nichols & Weedn (1986)
58	driver side impact	none	24	moderate, placental laceration, uterine laceration	stillborn	Weinstein & Pallais (1968)
59	driver front impact	none	39	none, placental laceration	stillborn	Pepperell et al. Case 2 (1977)
60	front passenger front impact	none	36	minor, placental laceration	stillborn	Ravangard & Porter (1980)
61	driver front impact severe crash	lap belt	34	moderate, placental laceration	stillborn	Stuart et al. Case 1 (1980)
62	driver front impact severe crash	none	28	minor, placental laceration	stillborn	Stuart et al. Case 2 (1980)
63	driver front impact severe crash	none	37	moderate, placental laceration	stillborn	Civil et al. (1988)
64	driver front impact	none	21	minor, placental laceration	stillborn	Stafford et al. Case 3 (1988)
65	front passenger	3-pt belt	36	moderate, placental laceration	head contusions	Griffiths et al. (1991)
66	driver front impact minor crash	none	37	minor, placental damage	skull fracture, brain hemorrhage	Cumming & Wren (1978)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
67	driver front impact	lap belt	33	minor, placental damage	skull fracture, brain hemorrhage	Stafford et al. Case 6 (1988)
68	driver front impact	none	32	minor, pelvic fx, placental damage	brain hemorrhages	Stafford et al. Case 7 (1988)
69	front passenger	3-pt belt	31	minor, placental damage	stillborn	Griffiths et al. (1991)
70	front passenger front impact	improper lap belt	20	none, uterine transection	transection	McCormick (1968)
71	driver rear impact	none	39	minor, uterine laceration	*emergency delivery, seizures, respiratory distress*	Galle & Anderson (1979)
72	driver front impact	none	20	minor, pelvic fx, uterine laceration	stillborn	Heitzman & Markarian (1970)
73	front passenger side impact	none	37	minor, pelvic fx, uterine laceration	stillborn	Smith et al. Case 2 (1994)
74	front passenger front impact	3-pt belt	30	minor, uterine rupture	strangled by cord	Svendsen & Morild (1988)
75	front passenger front impact severe crash	lap belt	24	minor, uterine rupture	stilllborn	Rubovits (1964)
76	driver front impact	restrained	22	minor, uterine rupture	stillborn	Pepperell et al. Case 9 (1977)
77	passenger side impact	restrained	30	minor, uterine rupture	stillborn	Pepperell et al. Case 14 (1977)
78	front passenger multiple impact	3-pt belt	32	moderate, uterine rupture	stillborn	Van Enk & Van Zwam (1994)
79	driver front impact	none	36	none	splenic rupture	Siddall-allum et al. (1991)
80	front passenger side impact	lap belt	24	minor	*spinal cord damage/paraplegia*	Weyerts et al. (1992)
81	front passenger side impact moderate crash	none	28	*major*	arm fracture	UMTRI GMP-002 (1996)
82	front passenger front impact severe crash	3-pt belt	30	minor	head, thorax, and abdomen hemorrhages	Fakhoury & Gibson (1986)
83	driver front impact severe crash	3-pt belt	27	none	cerebral hemorrhage, hepatic hemorrhage, hemoperitoneum	Fries & Hankins (1989)
84	driver side impact	none	27	pelvic fx	skull fracture, brain hemorrhages, thoracic hemorrhages	Sherer et al. (1993)
85	driver front impact	none	30	none	skull fracture	Pepperell et al. Case 3 (1977)
86	driver side impact severe crash	none	32	*moderate, pelvic fx*	skull fracture	Evrard et al. (1989)
87	driver front impact	restrained	30	moderate	brain hematomas	Ford & Picker (1989)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
88	front passenger side impact minor crash	none	37	minor	*brain hemorrhage, apnea, seizures*	UMTRI GMP-001 (1996)
89	driver side impact	3-pt belt	39	moderate, pelvic fx	*emergency C/S, brain contusion, seizures*	Matthews & Hammersly (1997)
90	driver front impact severe crash	none	25	minor	*contractions stopped w/o intervention, brain damage*	Knuppel et al. (1994)
91	front passenger front impact severe crash	none	28	minor	*hydrocephalus, possibly from crash*	UMTRI GMP-013 (1997)
92	driver minor crash	restrained + airbag	33	minor	*contractions stopped without intervention*	Sims et al. Case 3 (1996)
93	front passenger front impact moderate crash	3-pt belt + airbag	31	minor	*contractions stopped without intervention*	UMTRI GMP-009 (1997)
94	front passenger front impact	none	38	minor	amniotic membrane rupture	Parkinson Case 3 (1964)
95	front passenger front impact severe crash	none	24	*major*	stillborn	Agran et al. Case 1 (1986)
96	driver side impact severe crash	none	23	*major*	stillborn	UMTRI GMP-205 (1997)
97	driver front impact severe crash	3-pt belt	28	minor	stillborn	UMTRI GMP-206 (1995)
98	front passenger side impact severe crash	3-pt belt	22	*major*	stillborn	UMTRI GMP-212 (1997)
99	driver side impact	none	36	none	stillborn	Pepperell et al. Case 1 (1977)
100	passenger side impact	none	38	moderate	stillborn	Pepperell et al. Case 12 (1977)
101	passenger front impact	none	38	*major*	stillborn	Pepperell et al. Case 23 (1977)
102	passenger front impact	none	26	*major*	stillborn	Pepperell et al. Case 26 (1977)
103	front passenger front impact minor crash	none	39	moderate	*no complications*	UMTRI GMP-003 (1996)
104	driver side impact moderate crash	3-pt belt	20	minor, pelvic fx	*no complications*	UMTRI GMP-004 (1997)
105	driver front impact minor crash	airbag	23	minor	*no complications*	UMTRI GMP-005 (1997)

TABLE A.1 SUMMARY OF AUTOMOTIVE CRASHES INVOLVING PREGNANT OCCUPANTS

No.	Occupant Position Impact Direction Impact Severity	Restraint	Gest Age (wk)	Maternal Injuries (italics indicate maternal fatality)	Fetal Outcome (italics indicate fetal survival)	Case Source
106	driver side impact minor crash	3-pt belt	35	minor	*no complications*	UMTRI GMP-007 (1997)
107	front passenger front impact minor crash	3-pt belt	36	minor	*no complications*	UMTRI GMP-008 (1997)
108	driver side impact minor crash	3-pt belt + airbag	22	minor	*no complications*	UMTRI GMP-011 (1997)
109	front passenger side impact minor crash	3-pt belt	31	minor	*no complications*	UMTRI GMP-012 (1997)
110	driver front impact minor crash	3-pt belt + airbag	26	minor	*no complications*	UMTRI GMP-014 (1997)
111	driver front impact minor crash	3-pt belt + airbag	38	minor	*no complications*	UMTRI GMP-201 (1997)
112	driver front impact minor crash	airbag	38	moderate	*no complications*	UMTRI GMP-202 (1996)
113	front passenger front impact moderate crash	3-pt belt	38	minor	*no complications*	UMTRI GMP-203 (1996)
114	front passenger front impact minor crash	3-pt belt + airbag	36	minor	*no complications*	UMTRI GMP-204 (1996)
115	driver side impact minor crash	3-pt belt	40	none	*no complications*	UMTRI GMP-209 (1997)
116	driver rear impact minor crash	3-pt belt	37	minor	*no complications*	UMTRI GMP-210 (1997)
117	driver front impact moderate crash	3-pt belt + airbag	39	moderate	*no complications*	UMTRI GMP-211 (1997)
118	front passenger severe crash	restrained	?	none, pelvic fx	*no complications*	Levin & Edson (1994)
119	driver side impact minor crash	restrained + airbag	39	none	*no complications*	Sims et al. Case 1 (1996)
120	driver front impact moderate crash	restrained + airbag	35	minor	*no complications*	Sims et al. Case 2 (1996)