Fetal outcome in motor-vehicle crashes: effects of crash characteristics and maternal restraint

Kathleen DeSantis Klinich, PhD; Carol A. C. Flannagan, PhD; Jonathan D. Rupp, PhD; Mark Sochor, MD; Lawrence W. Schneider, PhD; Mark D. Pearlman, MD

OBJECTIVE: This project was undertaken to improve understanding of factors associated with adverse fetal outcomes of pregnant occupants involved in motor-vehicle crashes.

STUDY DESIGN: In-depth investigations of crashes involving 57 pregnant occupants were performed. Maternal and fetal injuries, restraint information, measures of external and internal vehicle damage, and details about the crash circumstances were collected. Crash severity was calculated using vehicle crush measurements. Chi-square analysis and logistic regression models were used to determine factors with a significant association with fetal outcome.

RESULTS: Fetal outcome is most strongly associated with crash severity ($P < .001$) and maternal injury ($P = .002$). Proper maternal belt-restraint use (with or without airbag deployment) is associated with acceptable fetal outcome (odds ratio = 4.5, $P = .033$). Approximately half of fetal losses in motor-vehicle crashes could be prevented if all pregnant women properly wore seat belts.

CONCLUSION: Higher crash severity, more severe maternal injury, and lack of proper seat belt use are associated with a higher risk of adverse fetal outcome. These results strongly support recommendations that pregnant women use properly positioned seatbelts.

Key words: airbags, crash investigations, fetal loss, pregnancy, seatbelts, wounds and injuries

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★ EDITORS' CHOICE ★

The public-health problem of fetal loss and injury from maternal involvement in motor-vehicle crashes is difficult to quantify. Reliable statistics on fetal loss resulting from automotive trauma are not available because maternal involvement in crashes has not been consistently recorded on fetal death certificates. In addition, the pregnancy status of women involved in crashes has only been tracked in national databases since 1995. The annual number of fetal losses resulting from automotive crashes in the United States is estimated to range from 90-369 fetal losses each year.[1] These estimates indicate that the actual number of fetal losses may be greater than the number of deaths to infants under 1 year from motor-vehicle crashes (154 in 2004).[2] Adverse fetal outcomes other than death can also occur as a result of trauma sustained in utero.[3,4] If a fetus survives a crash, complications resulting from the crash including emergency delivery of a premature fetus,[5] such as low birthweight and neonatal respiratory distress syndrome or fetal asphyxia, can lead to long-term physical or neurologic problems for the child.

Abruptio placentae (AP) is the leading cause of fetal loss in motor-vehicle crashes.[6] Although shear and tensile failure have been suggested as mechanisms that cause traumatic AP, the exact mechanism of placental separation caused by trauma is not certain. If reliable information about fetal loss was available, knowledge about the factors and circumstances surrounding fetal loss and injury in motor-vehicle crashes could be used to help vehicle restraint designers improve protection for pregnant occupants, and reduce the frequency and severity of adverse fetal outcomes. Published studies of pregnancy outcome after automobile crashes have generally not included complete and accurate information about crash severity and restraint use.[7-9] Moreover, the case reports in the literature generally emphasize crashes that result in negative fetal outcomes to illustrate particularly unusual or severe injuries, and generally do not reflect the typical spectrum of fetal

From the University of Michigan Transportation Research Institute (Drs Klinich, Flannagan, Rupp, Sochor, and Schneider) and the Department of Biomedical Engineering (Dr Schneider), University of Michigan, and the Departments of Emergency Medicine (Dr Sochor) and Obstetrics and Gynecology and Surgery (Dr Pearlman), University of Michigan Health Systems, Ann Arbor, MI.

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For Editors' Commentary, see Table of Contents

outcomes for pregnant occupants in crashes.[7,8,10,11] To improve vehicle safety for the pregnant population, cases that illustrate both positive and negative fetal outcomes after crashes provide more useful information than cases that focus only on unusual and severely adverse outcomes. The methodology for this research was documented in a preliminary report, although the current article describes a more detailed analysis of a larger database.[12]

The purpose of this study was to conduct in-depth investigations of motor-vehicle crashes involving pregnant occupants, with a focus on determining how restraint conditions and specific crash characteristics affect fetal outcome. Inclusion of crashes with both positive and adverse fetal outcomes, and with both belt-restrained and unbelted pregnant occupants, will provide a wider variety of cases than previously reported in the literature. In addition, providing quantitative information on the crash and maternal restraint conditions allows for more quantitative analysis of the data with regard to the causes of fetal injury or loss. Previous studies have demonstrated that pregnant women are more likely to properly wear seat belts when instructed to by their caregivers.[13-15] Therefore, the findings may help both medical practitioners and safety engineers reduce the number of fetal losses from motor-vehicle crashes through appropriate advice to pregnant women and improvements in vehicle restraint design.

Materials and Methods

Data from the crashes included in this study were collected in 2 phases. For the first part of the study, crashes with pregnant occupants* were identified through notifications from trauma centers and police agencies and responses to advertisements in medical facilities. Eighty-seven notifications were received over 30 months (Aug. 1996-Feb. 1999). Two-thirds of the notifications were from locations in the Southeast Michigan area, with the remaining notifications received from across the United States. Thirty-seven notifications were received from medical contacts, twenty-four from law-enforcement or crash-investigation sources, and the remaining 26 from responses to notices. Before participating in the study, each pregnant occupant (or her legal representative) signed institutional review board-approved consent forms.

Study subjects were included if they were at least 20 weeks' gestation, were involved in a motor-vehicle crash, and agreed to participate. Cases involving a rollover crash were not investigated. No other exclusion criteria were used. Of the 87 crash notifications, 10 were excluded because the fetus was less than 20 weeks' gestation. This exclusion criterion was chosen because the high frequency of spontaneous pregnancy loss before 20 weeks would make association of fetal loss with a motor-vehicle crash this early in pregnancy questionable. Six crashes were not investigated because they involved a rollover of the case vehicle, for which occupant kinematics and injury causations are difficult to determine. Twenty-nine crashes were not investigated because the pregnant occupant declined to participate. These exclusions resulted in a total of 42 crash investigations involving 43 pregnant occupants (1 crash involved 2 pregnant occupants). Each of the 43 occupants is considered a case.

In the second phase of the study, data on 14 crashes involving pregnant occupants were retrieved from 2 other sources. The Crash Injury Research Engineering Network (CIREN) is a database of occupants involved in motor-vehicle crashes that have sustained serious injury, while the University of Michigan Crash Investigation Program collects detailed data on approximately 100 crashes per year in a variety of crash conditions. When reviewing these 2 datasets, any case with a pregnant occupant that met the inclusion criteria and contained a record of fetal outcome was included in this study.

For the 57 cases in the resulting dataset, information about the crash circumstances and scene was obtained, external crush profiles of involved vehicles were measured, internal vehicle intrusions and contact marks were identified, vehicle interior and exterior damage was photographed and detailed information and injuries for the pregnant occupant and fetus were obtained from medical records. Restraint use was determined through subject interviews and examination of physical evidence during the vehicle inspection, such as markings on the belt webbing or D-ring that indicate loading in a crash. Crash severity was estimated by entering vehicle crush measurements into the Winsmash[16] crash-reconstruction program, which calculates the estimated change in velocity (ΔV) or equivalent barrier speed (EBS) of the case vehicle during the impact event. Because crashes with ΔV or EBS greater than 48 km/h are more severe than 95% of all crashes, crashes were classified as severe if the ΔV or EBS was greater than 48 km/h, moderate for ΔV or EBS of 24 to 48 km/h, and minor for ΔV or EBS less than 24 km/h.

Fetal outcome was evaluated within 1 month after birth, and did not include a longer-term evaluation. In some analyses, fetal outcomes were prospectively defined into separate outcome categories, including good, minor complications, major complications, or fetal loss. Minor complications include early contractions or delivery within 48 hours of the crash at a gestational age of at least 32 weeks. Major complications include abruptio placenta (diagnosed by delivering care provider), uterine rupture or laceration, any direct fetal injury, or premature delivery within 48 hours of the crash before 32 weeks' gestational age. In some analyses, fetal outcome was also prospectively defined and grouped into binary categories of either acceptable (good or minor complications) or adverse (major complications or fetal loss). Maternal injury was categorized by using the injury severity score (ISS),[17] excluding injuries to the placenta or uterus. A no-injury rating was assigned to ISS of 0, ISS from

*The rights, welfare, and informed consent of the volunteer subjects who participated in this study were observed under guidelines established by the US Department of Health and Human Services on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, Medical School, The University of Michigan.

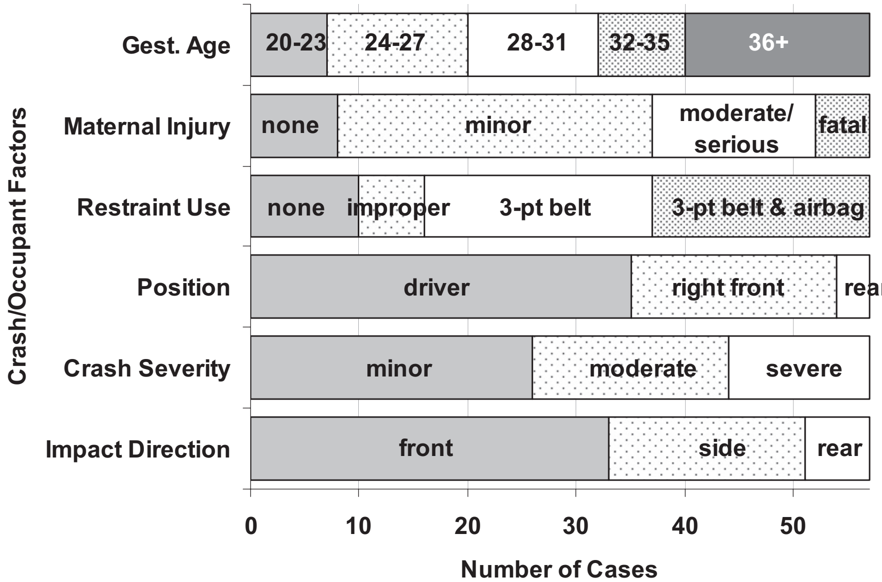
1-9 were designated minor, ISS from 10-20 were designated moderate, and a ISS greater than 20 designated as major. A fifth maternal injury category used was maternal death, regardless of ISS.

Chi-square tests were performed to determine whether fetal outcome and the various crash, occupant, and restraint factors are independent. For factors with statistically significant effects on fetal outcome, the pattern of the relationship was determined by inspection of standardized residuals.

For variables with a statistically significant relationship to fetal outcome, risk models were developed by using logistic regression routines in SPSS. For this analysis, restraint was grouped into binary categories of (1) proper (3-point belt or 3-point belt plus airbag) or (2) improper (unrestrained, airbag only, and shoulder belt only, with and without airbag.) None of the 57 cases involved the use of only a lap belt. According to standard practice in crash database analysis, this analysis was limited to frontal (n = 33) and near-side crashes (n = 15) because the number of rear (n = 5) and far-side impacts (n = 3) was small.

Case-control techniques were used to account for the oversampling of severe crashes in the dataset. The National Automotive Sampling System,[18] a stratified sample of crashes occurring in the United States, was used to estimate the number of pregnant women involved in frontal and near-side motor-vehicle crashes each year. This value was used with Weiss' estimate of 369 fetal deaths from motor-vehicle crashes per year[1] to estimate the frequency of fetal loss in motor-vehicle crashes. This estimate was used with case-control techniques[19] to adjust the intercept of the logistic regression models to estimate the risk of adverse fetal outcome as a function of crash severity and maternal restraint use. These data were also used to estimate the number of fetal losses that could be prevented by belt use.

FIGURE 1
Distribution of cases



Distribution of cases by key crash and occupant factors.

Klinich. Fetal outcome in motor-vehicle crashes. Am J Obstet Gynecol 2008.

RESULTS

Overview of crashes

Figure 1 shows the distributions of key independent variables in the 57 cases. The Appendix summarizes these variables and the fetal outcome for each case, grouped by impact direction, crash severity, and maternal restraint use because comparisons of fetal outcome according to maternal restraint use are most appropriately made among crashes with similar characteristics.

Twelve cases resulted in fetal loss. Four of these occurred in severe frontal impacts and 1 was in a moderate frontal impact (cases 2, 3, 4, 7, and 8, respectively). AP is thought to be the cause of fetal death in all 5 of these cases. Four of the remaining fetal losses (cases 38, 40, 43, and 44) resulted from maternal death in moderate-to-severe near-side impacts (vehicle struck on the side where the pregnant occupant is seated); 1 of these fetuses also sustained a fractured humerus. Another fetal loss from AP occurred to a seriously injured mother in a severe near-side impact (case 36). One fetal loss from maternal death occurred in a far-side impact (impact to the side opposite to where the occupant is seated) when the unbelted pregnant driver sustained fatal head injuries from contact with the vehicle interior on the passenger side (case 34). The remaining fetal loss (case 55) occurred when the fetus died in utero within 6 hours after a minor rear impact for unknown reasons without any signs of AP or direct fetal injury.

In 11 cases, the fetus survived but experienced major complications. In 1 minor frontal crash (case 22), the pregnant right-front passenger was improperly restrained by only a shoulder belt and exsanguinated from cardiac and splenic injuries. The infant was born by emergency cesarean delivery at 28 weeks and survived, although it suffered from respiratory distress syndrome (long-term outcome is not available). In 3 cases (1, 3, and 46), the fetus sustained in utero head injury as the primary adverse outcome. One of these cases (1) involved a pregnant, unrestrained rear-seat passenger who was lying in a prone position across the seat at the time of the crash. The fetus sustained a trauma-induced hydrocephaly. The other 7 cases with major fetal complications resulted in AP and/or uterine laceration with fetal survival (cases 5, 12, 31, 35, 39, 52, and 53).

All of the remaining 34 cases had acceptable fetal outcomes. One case (10) resulted in delivery of a healthy infant at 40 weeks on the day of the crash, 1 case led to a successful emergency caesarean delivery immediately after the crash (case 50), and 7 cases led to preterm con-

TABLE

Logistic regression models used to evaluate crash severity, maternal injury, and maternal restraint as predictors of fetal outcome

Model	Variable	−2 log (LR)	*P*-value	Odds ratio [95% CI]
1	Crash severity	43.341	<.001	1.097[a] [1.045-1.165]
2	Proper restraint	59.592	.009	4.545 [1.127-18.324]
3	Maternal injury	49.549	.002	3.002 [1.601-7.927]
4	Crash severity	39.491	.006	1.101 [1.028-1.179]
	Proper restraint		.049	9.257[1.006-85.195]
	Maternal injury		.266	1.624 [0.691-3.813]
5	Crash severity	36.767	<.001	1.120 [1.050-1.195]
	Proper restraint		.020	12.046 [1.485-97.658]

[a] Odds ratios for crash severity are for an increase of crash severity of 1 km/h.

Klinich. Fetal outcome in motor-vehicle crashes. Am J Obstet Gynecol 2008.

tractions that did not result in delivery. One case with a good fetal outcome (case 42) involved a moderate near-side impact to a pregnant driver wearing a 3-point belt who sustained multiple pelvic fractures. At the time of the crash, the fetus was 20 weeks' gestation, and sustained no injuries despite the compromised maternal pelvic cavity. She ultimately had an uncomplicated spontaneous vaginal delivery at 38.5 weeks' gestation without evidence of neonatal injury.

Of 41 properly restrained pregnant occupants, 12 (29%) experienced adverse fetal outcomes. Of 6 improperly restrained women, 3 (50%) had adverse fetal outcomes. For unrestrained women, 8 of 10 (80%) had adverse fetal outcomes. The only 2 acceptable fetal outcomes to unrestrained women were in crashes of minor severity. Overall, 11 of the 13 severe crashes resulted in poor fetal outcomes, regardless of restraint type.

Analysis of crashes

For this study, χ^2 tests show that fetal outcome is significantly associated with crash severity ($P = .005$), such that minor crashes are more likely to result in acceptable fetal outcomes, whereas severe crashes are more likely to produce adverse fetal outcomes. However, there are no significant relationships between fetal outcome and impact direction ($P = .782$) or fetal outcome and the position of the pregnant occupant in the vehicle ($P = .251$).

A χ^2 test also shows that fetal outcome is strongly associated with the severity of maternal injury ($P = .001$), with more serious fetal outcomes associated with more severe maternal injury. In this study, gestational age (grouped by 4-week increments) has a statistically significant effect on fetal outcome ($P = .009$), with the eighth month of pregnancy having a higher frequency of major complications than expected, and the fifth month having more good fetal outcomes than expected.

For analysis by maternal restraint use, 2 categories of proper and improper restraint were used because of the small number of each type of improper restraint. Proper restraint use is significant ($P = .006$) with unrestrained occupants less likely to have acceptable fetal outcomes and more likely to experience major complications. Women restrained by 3-point belts or 3-point belts plus airbags are less likely to have major complications than expected statistically. Both proper and improper restraint categories had close to the statistically expected number of fetal losses.

The most significant findings from the χ^2 tests are that fetal outcome is related to crash severity, maternal injury, and maternal restraint. Because these variables are not independent, logistic regression was used to analyze the combined contributions of these predictors to fetal outcome. The table shows 5 different models used to assess fetal outcome. Models 1, 2, and 3 show that crash severity, proper restraint, and maternal injury are all independently good predictors of fetal outcome. However, when all 3 are used as predictors simultaneously in model 4, maternal injury becomes insignificant, because maternal injury is also a function of crash severity ($P = .001$, odds ratio = 1.066 [1.027-1.105]). Model V predicts probability of adverse fetal outcome as a function of crash severity and proper restraint. (The odds ratio for crash severity indicates the increase in risk per km/h of crash severity; an increase in crash severity of 10 km/h corresponds to an odds ratio of 2.47).

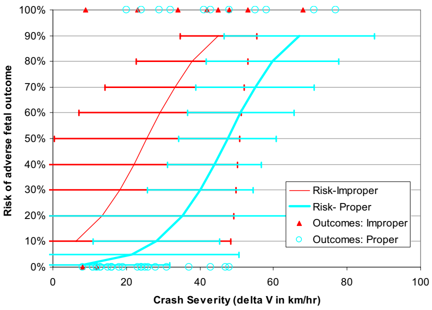
Figure 2 shows the results of model 5 after correcting the intercept in the logist function by using estimates of fetal loss from motor-vehicle crashes (population fetal loss rate 2.5% vs 21% in the current study). At a given crash severity, the risk of adverse fetal outcome for improperly restrained pregnant occupants is higher than that for properly restrained pregnant occupants. For example, at a crash severity of 30 km/h, the risk of adverse fetal outcome is about 12% for properly restrained pregnant occupants and about 70% for improperly restrained pregnant occupants.

These risk curves indicate that an 84% reduction in risk of adverse fetal outcome is obtained by properly wearing a seatbelt. On the basis of this relative risk and an overall belt use rate of 80%, unbelted pregnant occupants sustain an estimated 62% of all fetal losses in motor-vehicle crashes. Considering the annual estimate of 369 fetal losses, increasing the belt use rate of pregnant occupants from 80% to 100% would prevent approximately 192 fetal losses.

Comment

The database established in this study is the largest collection of motor-vehicle crashes involving pregnant women that includes detailed quantitative information about both the crash event and fetal outcome. Unlike the majority of case studies presented in the literature, crashes with both positive and negative fetal outcomes were investigated. In addition, the 72% belt usage rate in the sample population of pregnant occu-

FIGURE 2
Risk of adverse fetal outcome by crash severity



Risk of adverse fetal outcome by crash severity for properly restrained (light) and improperly restrained (dark) pregnant occupants based on logistic regression analysis. Each open circle represents a properly restrained case, whereas each filled triangle represents an improperly restrained case. Data points along the top of the graph (value = 100%) correspond to adverse outcome, whereas data points along the bottom of the graph (value = 0%) represent acceptable (ie, nonadverse) outcomes. Horizontal error bars indicate a 95% confidence interval.

Klinich. Fetal outcome in motor-vehicle crashes. Am J Obstet Gynecol 2008.

pants approaches current belt-restraint usage rates of 82% in the United States.[20] The sample also includes a greater number of pregnant women involved with airbag deployments than previously reported.[21]

Crash severity is the factor most strongly associated with fetal outcome in this study. Some case studies in the literature have suggested that belt or airbag restraints cause adverse fetal outcomes, but have not included information on crash severity.[7,11,22] Claims that restraints cause adverse fetal outcomes cannot be substantiated without reliable information on crash severity. This study also suggests that restraint use protects the fetus by protecting the mother, because maternal injury is predictive of fetal outcome, and proper restraint use reduces maternal injury severity.

The current study has several limitations. Rollovers were excluded because it is difficult to accurately assess belt use during in-depth investigations of rollovers.[23] Although the exclusion of rollover crashes could create a bias in assessment of restraint effects, rollovers account for only 2% of all crashes annually in the United States.[24] The effect of this exclusion is therefore expected to have minimal impact on the study findings. About one-third of the identified pregnant women in crashes declined to participate in the study, creating a potential for selection bias. However, a review of the investigated and excluded crashes, though limited by estimated and missing information in the excluded crashes, suggests that the distributions of key independent variables (listed in Figure 1) are similar for the included and excluded cases.

The limited size of the database, and the nonrandom sampling process are likely the source of some unexpected findings and limit the extent to which conclusions should be applied to the general population. The finding that crash direction is not associated with fetal outcome is unexpected, because the likelihood, severity, and patterns of injury for nonpregnant occupants have been shown to depend on impact direction.[25] This result suggests that the limited number of cases in the study probably does not include a representative selection of side and rear impacts.

In addition, the database is biased toward severe crashes and subsequently has a greater proportion of adverse fetal outcomes than expected in the general population. Less than 1% of all real-world crashes have severities greater than 48 km/h (personal correspondence, Compton, C. University of Michigan Transportation Research Institute, May, 2007), whereas 18.6% of the crashes in this database have severities greater than 48 km/h. However, the method of using case-control techniques to adjust the logistic regression intercept to account for the oversampling of severe crashes can aid in resolving the sampling issue. Breslow[19] has stated that even if a sample is biased toward more severe cases, logistic regression produces unbiased estimates of the odds ratios for predictors. With a sample biased toward more severe cases, the intercept will be biased upward and absolute risk will be overestimated, but relative odds will be unbiased. However, the use of an outside estimate of overall population risk can be used to adjust the logist function intercept and correct the absolute risks.

Within these recognized limitations, it was important to evaluate the effect of airbag deployment on fetal and maternal outcome, because widespread use of this restraint is relatively new. Although limited by the small number of cases, the data from this study suggest that restraint by an airbag plus a 3-point belt leads to fetal outcomes that are as good as restraint only by a 3-point belt. The important point of this finding is that airbags do not appear to worsen fetal outcomes.

The risk of adverse fetal outcomes estimated from the data are higher than, but consistent with, estimated fetal loss rates reported in the literature of 1% to 2% in minor severity crashes[26-28] and 30% to 50%[29-31] in severe crashes. Assuming that the qualitative definitions of minor and severe crashes in the literature are similar to the quantified definitions used in this study, the risk values in the current study include all adverse fetal outcomes, including but not limited to fetal loss from AP, whereas some of the values from the literature are based only on fetal losses resulting from AP. By using the results shown in Figure 2, the risk of adverse fetal outcome for properly restrained pregnant occupants is less than 10% in minor crashes and more than 60% in severe crashes.

A better understanding of the factors contributing to fetal loss in motor-vehicle crashes will help guide medical practitioners in providing appropriate advice to pregnant patients on the proper use of vehicle restraints. Currently, the main reason for recommending that pregnant occupants use three-point belts is that protecting the mother is the first step to protecting the fetus, and that using seat belts significantly reduces injury risk for the general vehicle-occupant population.[32] However, the practice of recommending that pregnant patients be instructed to properly use 3-point belts[33] has been questioned by some practitioners because the medical literature contains isolated cases of fetal injuries allegedly caused by seat belt loading in crashes.[34,35] Also, questions regarding the safety of deploying airbags for pregnant women have been raised. This study shows that proper use of a belt restraint by the pregnant occupant has a significant, positive effect on fetal outcome. Seventy-nine percent of the pregnant women who were properly wearing a 3-point belt, with or without airbag deployment, had acceptable fetal and maternal outcomes in lower severity crashes. An estimated 192 fetal losses could be prevented each year if all pregnant women properly wore seatbelts. The strong association between maternal injury and fetal outcome, particularly for the 4 cases of maternal death to unrestrained or improperly restrained women, supports previous observations that protecting the mother is the first step in protecting the fetus.[36] The results or this study support the current recommendation that pregnant women should properly wear 3-point belts. ■

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REFERENCES

1. Weiss HB, Songer TJ, Fabio A. Fetal deaths related to maternal injury. JAMA 2001;286 (15):1863-8.
2. Minino A, Heron M, Smith B. Deaths: preliminary data for 2004. Natl Vital Stat Rep 2006;54(19):1-49.
3. Baethman M, Kahn T, Lenard H-G, Voit T. Fetal CNS damage after exposure to maternal trauma during pregnancy. Acta Paediatr 1996;85(11):1331-8.
4. Weyerts LK, Jones MC, James HE. Paraplegia and congenital contractures as a consequence of intrauterine trauma. Am J Med Gen 1992;43(4):751-2.
5. Kettel LM, Branch DW, Scott JR. Occult placental abruption after maternal trauma. Obstet Gynecol 1988;71(3 pt 2):449-53.
6. Pearlman M, Tintinalli JE, Lorenz RP. Blunt trauma during pregnancy. N Engl J Med 1990;323:1609-13.
7. Pepperell RJ, Rubinstein E, MacIsaac IA. Motor-car accidents during pregnancy. Med J Aust 1977;1(7):203-5.
8. Lane PL. Traumatic fetal deaths. J Emerg Med 1989;7(5):433-5.
9. Wolf ME, Alexander BH, Rivara FP, Hickok DE, Maier RV, Starzyk PM. A retrospective cohort study of seatbelt use and pregnancy outcome after a motor vehicle crash. J Trauma 1993;34(1):116-9.
10. Hartl R, Ko K. In utero skull fracture: case report. J Trauma 1996;41(3):549-52.
11. Van Enk A, Van Zwam W. Uterine rupture: a seat belt hazard. Acta Obstetr Gynecol Scand 1994;73(5):432-3.
12. Pearlman M, Klinich K, Schneider LW, Rupp J, Moss S, Ashton-Miller J. A comprehensive program to improve safety for pregnant women and fetuses in motor vehicle crashes: a preliminary report. Am J Obstet Gynecol 2000;182(6):1554-64.
13. Pearlman M, Phillips ME. Safety belt use during pregnancy. Obstet Gynecol 1996; 88(6):1026-9.
14. McGwin G Jr, Russel SR, Rux RI, Leath CA, Valent F, Rue LW. Knowledge, beliefs, and practices concerning seat belt use during pregnancy. J Trauma 2004;56(3):670-5.
15. McGwin G Jr, Willey P, Ware A, Kohler C, Kirby T, Rue LW 3rd. A focused educational intervention can promote the proper application of seat belts during pregnancy. J Trauma 2004; 56(5):1016-21.
16. WinSmash. Release 2.06x. Washington, DC:NASS; 1999.
17. Baker SP, O'Neill B, Waddon W Jr, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating care systems. J Trauma 1974;14:186-7.
18. Weiss HB, Strotmeyer S. Characteristics of pregnant women in motor vehicle crashes. Inj Prev 8(3):207–10.
19. Breslow NE. Statistics in epidemiology: the case-control study. J Am Stat Assoc 1996; 91(433):14-28.
20. Traffic Safety Facts 2005. Washington, DC: National Highway Traffic Safety Administration, NHTSA; 2005. Report No.: DOT HS 810 623.
21. Sims CJ, Boardman CH, Fuller SJ. Airbag deployment following a motor vehicle accident in pregnancy. Obstet Gynecol 1996;88(4 pt 2): 726.
22. Schultze PM, Stamm CA, Roger J. Placental abruption and fetal death with airbag deployment in a motor vehicle accident. Obstet Gynecol 1998;92(4):719.
23. Robertson L. Further reflections on the seatbelt use and effectiveness issue. Inj Prev 2003;(9):284-5.
24. Traffic Safety Facts 1998. Washington, DC: National Highway Traffic Safety Administration, NHTSA; 1988. Report No.: DOT HS 808 983.
25. Thomas C, Henry C, Hartemann F, Patel A, Got C. Injury pattern and parameters to assess severity for occupants involved in car-to-car lateral impacts. Proceedings of the 11th International Conference for the Enhanced Safety of Vehicles; 1988; Washington, DC.
26. Dahmus MA, Sibai BM. Blunt abdominal trauma: are there any predictive factors for abruptio placentae or maternal-fetal distress? Am J Obstet Gynecol 1993;169(4):1054-8.
27. Pearlman MD, Tintinalli JE, Lorenz RP. A prospective controlled study of outcome after trauma during pregnancy. Am J Obstet Gynecol 1990;(162):1502-10.
28. Goodwin TM, Breen MT. Pregnancy outcome and fetomaternal hemorrhage after noncatastrophic trauma. Am J Obstet Gynecol 1990;162(3):665-71.
29. Esposito TJ, Gens DR, Smith LG, Scorpio R, Buchman T. Trauma during pregnancy: a review of 79 cases. Arch Surg 1991;(126): 1073-8.
30. Hoff WS, D'Amelio LF, Tinkoff GK, Lucke JF, Rhodes M, Diamond DL. Maternal predictors of fetal demise in trauma during pregnancy. Surg Gynecol Obstet 1991;172(3):175-80.
31. Rothenberger D, Quattlebaum FW, Perry JF Jr, Zabel J, Fischer RP. Blunt maternal trauma: a review of 103 cases. J Trauma 1978;18 (3):173-9.
32. Viano DC. Restraint effectiveness, availability and use in fatal crashes: implications to injury control. J Trauma 1995;38(4):538-46.
33. American College of Obstetricans and Gynecologists. Obstetric aspects of trauma management. ACOG Educational Bulletin 1998: 251.
34. Astarita DC, Feldman B. Seat belt placement resulting in uterine rupture. J Trauma 1997;42(4):738-40.
35. Chetcuti P, Levene M. Seat belts: a potential hazard to the fetus. J Perinat Med 1987;15(2):207-9.
36. Crosby WM, Costilow JP. Safety of lap-belt restraint for pregnant victims of automobile collisions. N Engl J Med 1971;284:632-6.

APPENDIX

The cases are grouped by impact direction, impact severity, and restraint use. Impact severity is categorized as minor (<24 km/h), moderate (24-48 km/h), or severe (>48 km/h). Gestational age is grouped into 4-week intervals to allow for comparisons based on anatomical differences.

CHARACTERISTICS AND FETAL OUTCOMES OF CRASHES INVOLVING PREGNANT OCCUPANTS

Case	Impact direction	Impact severity	Occupant restraint	Occupant position	Gest. age (wk)	Maternal injuries	Fetal outcome
1	Front	Severe	None	Left rear	28-31	Moderate	Fetal hydrocephalus from intraventricular hemorrhage, probably from crash
2	Front	Severe	Shoulder belt and airbag	Driver	36+	Moderate	Fetal loss, placental abruption
3	Front	Severe	3-pt belt	Driver	28-31	Minor	Fetal loss
4	Front	Severe	3-pt belt	Driver	36+	Moderate	Fetal loss, placental abruption
5	Front	Severe	3-pt belt and airbag	Driver	24-27	Moderate	Placental abruption, emergency C-section, 27-week premature delivery
6	Front	Severe	3-pt belt and airbag	Driver	28-31	Major	No problem
7	Front	Severe	3-pt belt and airbag	Driver	28-31	Moderate	Fetal loss, placental abruption
8	Front	Moderate	3-pt belt	Driver	24-27	None	Fetal loss, placental abruption, early delivery
9	Front	Moderate	3-pt belt	Right front	36+	None	Contractions stopped without intervention
10	Front	Moderate	3-pt belt	Right front	36+	Minor	Delivery within 48 hours
11	Front	Moderate	3-pt belt and airbag	Right front	24-27	Minor	No problem
12	Front	Moderate	3-pt belt and airbag	Driver	24-27	Minor	Premature birth, respiratory distress, placental abruption, apnea, intraventricular hemorrhage
13	Front	Moderate	3-pt belt and airbag	Right front	28-31	Moderate	Fetal head injury, probably from crash
14	Front	Moderate	3-pt belt and airbag	Driver	32-35	Moderate	Premature labor requiring intervention
15	Front	Moderate	3-pt belt and airbag	Right front	36+	Minor	No problems
16	Front	Moderate	3-pt belt and airbag	Driver	36+	Minor	No problems
17	Front	Moderate	3-pt belt and airbag	Driver	36+	Minor	No problems
18	Front	Minor	None	Driver	20-23	Minor	No problems
19	Front	Minor	None	Right front	36+	Minor	No problems
20	Front	Minor	Airbag	Driver	20-23	Minor	No problems
21	Front	Minor	Airbag	Driver	36+	Minor	Contractions stopped at hospital
22	Front	Minor	Shoulder belt	Right front	28-31	Major (fatal)	Premature birth, fetal respiratory distress

(Cont'd)

Case	Impact direction	Impact severity	Occupant restraint	Occupant position	Gest. age (wk)	Maternal injuries	Fetal outcome
23	Front	Minor	3-pt belt	Driver	20-23	Minor	No problems
24	Front	Minor	3-pt belt	Driver	24-27	None	No problems
25	Front	Minor	3-pt belt	Driver	24-27	Minor	No problems
26	Front	Minor	3-pt belt	Rear pass	24-27	None	No problems
27	Front	Minor	3-pt belt and airbag	Driver	24-27	Minor	No problems
28	Front	Minor	3-pt belt and airbag	Driver	24-27	Minor	No problems
29	Front	Minor	3-pt belt and airbag	Driver	28-31	Minor	Contractions stopped without intervention
30	Front	Minor	3-pt belt and airbag	Right front	28-31	Minor	Contractions stopped without intervention
31	Front	Minor	3-pt belt and airbag	Driver	32-35	Minor	Uterine lacerations, placental abruption, fetal respiratory distress, early delivery
32	Front	Minor	3-pt belt and airbag	Driver	36+	Minor	No problems
33	Front	Minor	3-pt belt and airbag	Right front	36+	Minor	Contractions stopped at hospital
34	Side	Severe	None	Driver	20-23	Major (fatal)	Fetal loss (twins)
35	Side	Severe	Airbag	Driver	32-35	Moderate	Uterine laceration, emergency C-section at 33 weeks, premature delivery
36	Side	Severe	3-pt belt	Driver	24-27	Major	Fetal loss, placental abruption
37	Side	Severe	3-pt belt and airbag	Right front	36+	Minor	No problems
38	Side	Moderate	None	Right front	28-31	Major (fatal)	Fetal loss, fetal arm fracture
39	Side	Moderate	None	Right front	32-35	Major	Placental abruption, emergency C-section, premature delivery
40	Side	Moderate	None	Right front	36+	Moderate (fatal)	Fetal loss, placental abruption, emergency C-section
41	Side	Moderate	Airbag	Right front	20-23	Minor	No problems
42	Side	Moderate	3-pt belt	Driver	20-23	Moderate	No problems
43	Side	Moderate	3-pt belt	Right front	24-27	Major (fatal)	Fetal loss
44	Side	Moderate	3-pt belt	Right front	28-31	Major (fatal)	Fetal loss
45	Side	Moderate	3-pt belt and airbag	Driver	28-31	Major	No problems
46	Side	Minor	None	Right front	36+	Minor	Early delivery, fetal head injury
48	Side	Minor	3-pt belt	Driver	32-35	Minor	No problems
49	Side	Minor	3-pt belt	Driver	36+	None	No problems
50	Side	Minor	3-pt belt	Driver	36+	Moderate	Emergency C-section immediately after crash

(Cont'd)

Case	Impact direction	Impact severity	Occupant restraint	Occupant position	Gest. age (wk)	Maternal injuries	Fetal outcome
47	Side	Minor	3-pt belt	Right front	28-31	None	No problems
51	Side	Minor	3-pt belt and airbag	Driver	20-23	Minor	No problems
52	Rear	Severe	None	Right front	32-35	Minor	Placental abruption, early delivery
53	Rear	Severe	None	Rear pass	32-35	Minor	Placental abruption, early delivery, possible fetal head injury
54	Rear	Minor	3-pt belt	Driver	24-27	Minor	No problems
55	Rear	Minor	3-pt belt	Driver	24-27	None	Fetal loss
56	Rear	Minor	3-pt belt	Driver	32-35	None	No problems
57	Rear	Minor	3-pt belt	Driver	36+	Minor	Contractions stopped without intervention