Impact Injury to the Pregnant Female and Fetus in Lap Belt Restraint

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Abstract

Although it has been well-established that the lap (seat) belt offers considerable protection against injury or death in crash environments, there has long been controversy over the injury potential to the pregnant female. This question is of importance in consideration of restraint and seat protective environments for both aircraft and automotive vehicles. Most of the four million pregnant women per year in the United States travel by automobile, with a large number traveling by commercial civil aircraft or the Military Air Transport Service. Thus, a sizable population is involved.

This combined study by the Civil Aeromedical Institute, FAA, 6571st Aeromedical Research Laboratory, Holloman AFB, and the University of Oklahoma School of Medicine has been concerned with the clinical, experimental, and applied aspects. Tests utilizing pregnant baboons (*Papio doguera*) have been run on the Holloman AFB Daisy Decelerator, and clinical case histories have been obtained in automotive accidents involving late-term pregnant women through cooperation of the California and Oklahoma Highway Patrol and individual obstetricians. This paper outlines the medical evidence for concern and notes the experimental findings to date.

THE LAP (SEAT) BELT offers considerable protection against injury in impact accidents, although little is known of its effects on the pregnant mother and her fetus (Ref. 1). In the United States, most women travel by automobile at one time or another during their pregnancy (Refs. 2, 8). A large number also travel as passengers in commercial or private aircraft and, as dependents, on planes of the Military Air Transport Service (Refs. 3, 4, 9). The present study was initiated to determine the effects of abrupt deceleration on the mother and her fetus when restrained by a lap belt.

To our knowledge, only one such case, involving a woman in the sixth month of pregnancy, has been reported in the literature (Ref. 5). This patient, with her seat belt properly secured, was riding in the front passenger seat of an automobile traveling about 35 mph when it was struck from the right front by another car. Surgical exploration revealed a 6 cm laceration of the uterus through which the fetus had been expelled by the force of impact. A dead fetus was delivered and the mother survived. Unfortunately, the risk of exposure and frequency of this type of accident cannot yet be assessed due to the absence of any reliable statistical data. Some indication of the scope of the problem can be gained from the fact that we have been able to collect 15 such cases in the course of a two-month effort. Six of these resulted in fetal demise. While relatively rare at the present time, we can expect them to become more frequent as the seat belt gains wider acceptance by the traveling public.

The data presented here constitute the first experimental approach to the subject.

Methods

For this study, a series of seven animal impact tests was conducted on the Daisy Deceleration Track at Holloman AFB, New Mexico. Female Kenya baboons (*Papio doguera*) were utilized as experimental animals. This primate has a uterus simplex and a gestation period of about 180 days. The adult females average about 13 kg in body weight and a full-term infant may weigh 500-1000 grams.

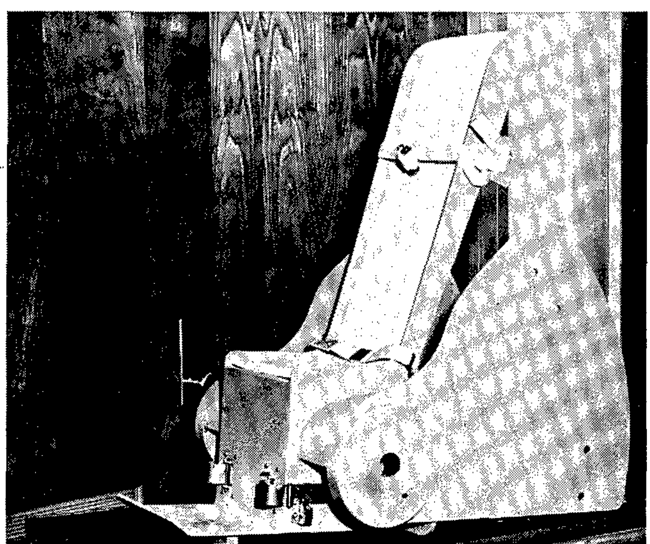

Fig. 1—Baboon restraint chair used in study with ankle and shoulder restraints designed to release at onset of sled movement so that animal can "jackknife" normally at impact

A seat scaled to fit the baboon was constructed (Figs. 1 and 2). The seat was oriented in the 45 deg (0-45-0) forward facing position. A 2 in. ensolite seat cushion was added to prevent iliac fracture. The seat belt consisted of 1½ in. 4500 lb test nylon webbing, adjusted statically on the seated animal to 1.5 kg (Fig. 3) by a tensiometer. Strain gages were mounted on each side of the lap belt. Belt angle was 55 deg, typical of commercial installation. A standard 14 x 17 in. X-ray cassette was mounted on the left side of the seat. Animals were restrained in modified children's denim jackets.

To date, seven tests involving six animals have been conducted. In addition, a sham test (without a sled run) was performed as a control of artifacts due to surgical and prerun restraint procedures. In Test 1 and in the sham test, Sernalyn® (Parke, Davis and Co.) anaesthesia was employed at a dosage of 1 mg/kg body weight, administered intramuscularly. Innovar-Vet® (McNeil Laboratories, Inc.) was used for anaesthesia in Tests 2-6 in 1.5 cc intramuscular dosages. In Test 7, Nembutal, in a dosage of 35 mg/kg body weight, was used in an attempt to avoid the known adrenergic effects of Innovar-Vet. In all tests, approximately 4 hr elapsed between initial anaesthesia and impact, so that some measure of normal muscle tonus was regained.

Intrauterine pressure, maternal EKG, fetal EKG, and maternal blood pressure were recorded with an 8-channel Sanborn and Ampex CF-100 tape recorder. In all instances, maternal blood pressure monitoring failed at impact, and post-impact data on this variable were obtained by periodic sphygmomanometer readings. In addition to these physiological variables, CEC tracings of the seat belt tensions and the g-profile were recorded.

Photographic documentation included lateral and overhead 16 mm motion picture at 2000 fps, black-and-white still coverage of pre- and post-run procedures, and 35 mm color photographs of gross trauma. To study body organ

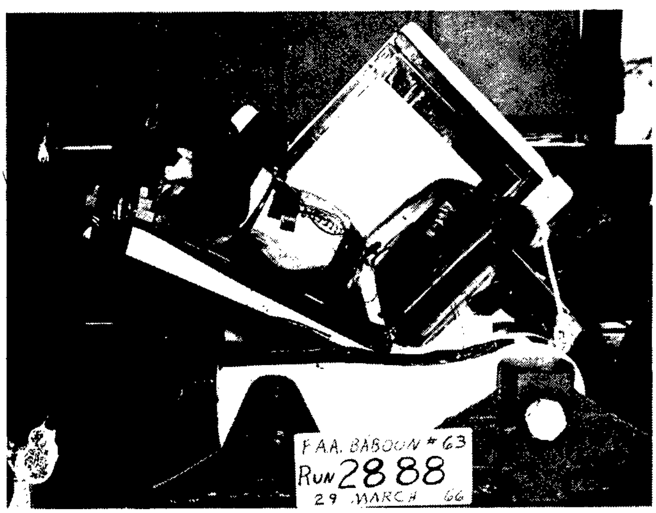

Fig. 2–Fully instrumented and anaesthetized pregnant baboon seated in restraint chair prior to impact

displacement at impact, a field Emission Flexitron Flash X-ray System was triggered at 0.065 sec after entrance of the sled into the water brake. Post-run whole body X-rays were taken on each animal.

The purpose of Test 1 was to establish techniques, test procedures, and deceleration patterns for subsequent experiments. The subject was not pregnant and physiological monitoring was not attempted. The subjects of Tests 2-4 were also nonpregnant but, in these animals, a simulated uterus was implanted. The latter consisted of a rubber balloon enclosed in nylon netting and contained a transducer to measure pressure changes during deceleration. It contained sufficient fluid (approximately 500 cc normal saline) to give a baseline pressure to 10 mm Hg. For Tests 5-7, pregnant females were used. In these animals, the uterus was opened and the pressure transducer introduced. EKG leads were also implanted into the scalp and elbow of the fetus (Fig. 4). To avoid piercing the placenta with implanted leads, the placenta had been localized previously by means of Technitium-99 scanning. Lost amniotic fluid was replaced, and the uterine and abdominal incisions closed.

The deceleration pattern in Test 1 was 40 g at 4000 g/sec rate of onset and a plateau duration of 0.080 sec at 87 fps entrance velocity. This pattern was derived from a program designed to compute the decelerative forces sustained by a typical passenger in a hypothetical Boeing 720 type airliner crashing on takeoff. As will be seen, this pattern proved to be nonsurvivable, and in Tests 2-7, the pattern was changed to a 20 g, 2000 g/sec rate of onset and a plateau duration of 0.080 sec.

Results

TEST 1 (Daisy Run 2880)—The subject was a nonpregnant female. This animal was a control used to evaluate equipment and procedures and to deter-

Fig. 3—Attachment of seat belts at rear of seat and initial adjustment at 1.5 kg

mine the feasibility of the impact profile. The animal was anaesthetized with Sernalyn 1 mg/kg body weight. No physiological variables were recorded. Impact entrance velocity was 87 fps with a 40 g peak at 4000 g/sec rate of onset, and a plateau duration of 0.080 sec. The animal was killed by the impact. High-speed photography demonstrated severe whiplash kinematics Autopsy revealed a complete transection of the cord and total subluxation of the atlanto-occipital joint. The vertebral arteries were ruptured bilaterally with massive hemorrhage into the soft tissue of the neck and superior mediastinum. Both ilia were transversely fractured, a finding considered artifactitious inasmuch as the essentially quadrupedal type pelvis of the baboon coupled with its poor gluteal development make it particularly liable to such fractures when a lap restraint is used without compensatory subischial seat padding. The uterus of this animal was sheared from its major anterior pelvic support.

Because of the extensive trauma, it was decided that the deceleration profile was too severe. Seat padding and a headrest were added to the seat. Innovar-Vet was substituted for Sernalyn in subsequent tests because the latter drug appeared to depress muscle tonus for an inordinate length of time.

Test 2 (Daisy Run 2882)—This test was run with a nonpregnant female baboon with a surgically implanted artificial uterus. The subject was anaesthetized with 1.5 cc Innovar-Vet administered approximately 4 hr before the run. The test profile was 20 g, 63.1 fps entrance velocity at 1500 g/sec rate of onset, with a plateau duration of 0.080 sec. In order to determine the intra-

Fig. 4—Surgical implantation of EKG leads in scalp and elbow of fetus

uterine pressure changes to be expected in the gravid uterus, pressure changes in the simulated uterus were monitored. From a baseline pressure of 10 mm Hg, the "intrauterine" pressure rose to 380 mm Hg at which time the leads became disconnected and no further data were recorded. Again, bilateral fracture of the ilia occurred because of insufficient seat padding. For subsequent tests, more seat padding was added.

TEST 3 (Daisy Run 2885)—The subject was a nonpregnant female baboon with artificial uterus. Innovar-Vet anaesthetic was injected 4 hr prior to impact. The deceleration profile was 20 g, at 60.3 fps entrance velocity at 2000 g/sec rate of onset, with a plateau duration of 0.080 sec. The temporary shoulder restraint did not release prior to impact; thus, the animal was impacted with an effective shoulder harness as well as lap belt restraint. Baseline intrauterine pressure measured 125-150 mm Hg with a single peak of approximately 500 mm Hg occurring approximately 0.055 sec after impact (Fig. 5).

TEST 4 (Daisy Run 2886)—The subject was the same animal as in Test 3, utilized again after there appeared to be no ill effects from the first impact. The deceleration pattern was identical, providing an excellent comparison of the effects of seat belt with the effects of seat belt and shoulder harness. Artificial uterus pressure showed a double peak. The first occurred at 400 mm Hg over baseline, dropping to 130 mm Hg below baseline and peaking again at 470 mm Hg. The first peak occurred at 0.050 sec and the second at 0.195 sec after the onset of deceleration. Post-impact bradycardia was observed in this animal. Autopsy revealed minor trauma consisting of a hematoma in the right inguinal canal and rupture of the falciform ligament of the liver (Fig. 6).

TEST 5 (Daisy Run 2888)—The subject was a 160-day pregnant baboon, impacted at 20 g, 60.3 fps entrance velocity, 2000 g/sec rate of onset, with a plateau duration of 0.080 sec. Transient post-run bradycardia was observed in both the mother and fetus. As the sled was accelerated, the intrauterine pres-

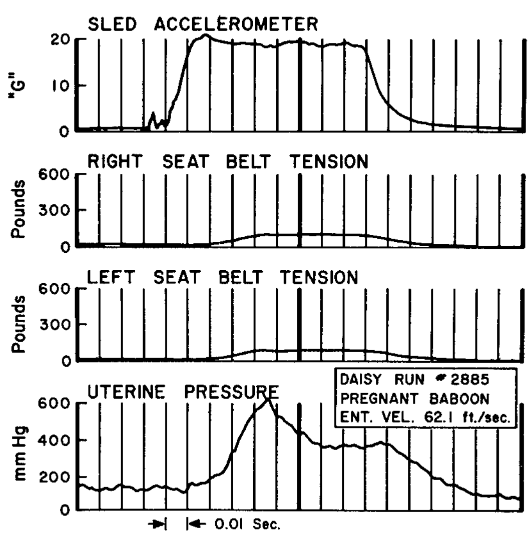

Fig. 5—Results of impact test No. 3 (Daisy Run No. 2885)

sure rose to 60 mm Hg over baseline. It peaked at 240 mm Hg over baseline at 0.055 sec after the onset of deceleration. It then dropped to 145 mm Hg and rose to a second peak of 420 mm Hg at 0.145 sec. Autopsy of the mother revealed subchorionic hemorrhage, subserosal petechiae in the wall of the jejunum, and separation of the right sacroiliac joint. No trauma to the fetus was observed (Fig. 7).

TEST 6 (Daisy Run 3013)—The subject was a pregnant baboon with a gestation time of approximately 140 days. She was impacted at 20 g, 2000 g/sec onset rate, with a plateau duration of 0.080 sec. In this animal, the intrauterine pressure rose to 60 mm Hg during the early phase of acceleration, but dropped back to baseline (10 mm Hg) immediately prior to impact. Following the onset of deceleration, it rose to 65 mm Hg above baseline at 0.050 sec. This was followed by a strong negative pressure of 380 mm Hg, 0.090 sec after onset of sled deceleration, and a second positive peak of 440 mm Hg at 0.145 sec, returning to baseline at 0.210 sec. A transient maternal and fetal bradycardia was again noted.

Although there was no immediate clinical evidence of injury to mother or fetus, fetal heartbeat could no longer be elicited approximately 1½ hr postrun, and the baby was stillborn at caesarian section. Autopsy of the fetus revealed no gross or microscopic signs of trauma. The mother recovered without complications.

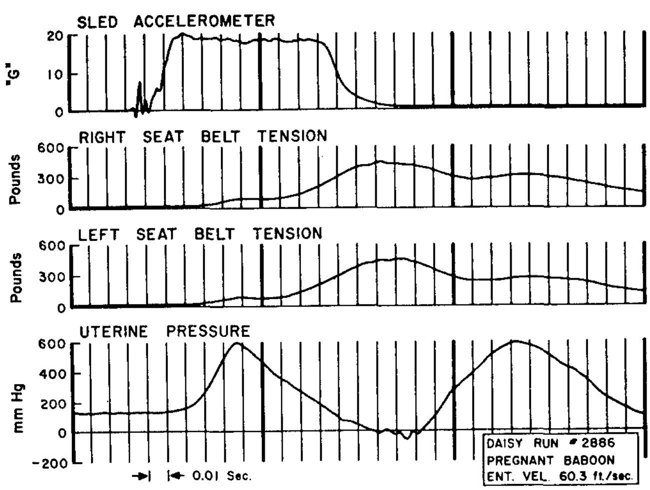

Fig. 6—Results of impact test No. A-4 (Daisy Run No. 2886)

Table 1—Mean Maternal and Fetal Heart Rates for Pregnant Animals Subjected to Impact

Time	Maternal, r/min.	Fetal, r/min.
Prerun	167	150
Post-Impact	73	57
2 Minutes	153	71
5 Minutes	160	110
20 Minutes	160	140

TEST 7 (Daisy Run 3062)—The subject was a 110-day pregnant baboon impacted at 20 g, 2000 g/sec rate of onset, with a plateau duration of 0.080 sec. Nembutal anaesthesia was given at a dosage of 35 mg/kg approximately 4 hr prior to impact. Intrauterine pressure rose approximately 15 mm Hg above baseline during acceleration. At 0.050 sec after the onset of deceleration, it peaked at 180 mm Hg, following which a drop of 560 mm Hg below baseline occurred at 0.135 sec. A second positive peak was of 140 mm Hg at 0.185 sec. Transient mother and fetal bradycardia were again observed.

As in the previous test, no discernible external trauma to the mother was observed but, at 1½ hr, post-impact fetal heart rate could no longer be recorded or heard, and caesarian section produced a stillborn baby. Ecchymotic areas were irregularly distributed on the head and upper torso of the fetus. Further autopsy results are pending. The mother was found in moribund shock in its cage the following morning, and died in shock approximately 20 hr after impact. Autopsy results are not yet available.

TEST 8 (Sham Run)—The subject of this experiment was a 145-day pregnant baboon. After Sernalyn anaesthesia, she was subjected to the same instrumentation and restraint procedures used in the previous tests without, however, being impacted. During this procedure, the amniotic sac was inadvert-

Fig. 7—Fetus with placenta attached (Although no clinical evidence of trauma was observed, impact was fatal to fetus)

ently ruptured. Following closure, the animal was returned to her cage. No change in fetal heart rate or maternal blood pressure was noted during the procedure. The next morning, however, the fetus was found dead in the cage. Autopsy revealed the animal to have been stillborn. The cause of intrauterine death was a subdural hemorrhage which is apparently a birth injury. It is planned to repeat this control procedure at a later date.

Seat Belt Forces—Forces on the right and left sides of the seat belt were measured for all impacts except Test 1. In Tests 2, 4, 5, 6, and 7, the results were essentially symmetrical and ranged from 450-640 lb with a mean of 516 lb. The peak in belt force occurred between 0.105-0.135 sec after the onset of deceleration. In strong contrast are the results from Test 3, in which the shoulder restraint failed to release. In this test, forces were recorded at 80 lb for both right and left belts (Fig. 8).

Discussion

From these preliminary data, it is apparent that the sequence of events following impact of the pregnant baboon in the 0-45-0 position is as follows:

1. During acceleration, the awake animal tenses the abdomen, raising the intrauterine pressure prior to impact.

2. At approximately 0.050 sec after the onset of deceleration, the animal is pressed into the seat, causing a rise in intrauterine pressure *before* "jack-knifing" begins.

3. Following the initial positive peak, the intrauterine pressure drops sharply at about 0.100 sec and then rebounds to a second, positive peak averaging about 400 mm Hg at about 0.170 sec. This second peak is attributed to the sudden impingement of the uterus between the belt and the spine when the animal is fully flexed anteriorly (Fig. 9).

This analysis is supported by the absence of the second peak in intrauterine pressure observed in Test 3 in which the shoulder harness failed to release. It is interesting to note, however, that in this animal the maximum uterine pressure was 500 mm Hg, or very similar to those animals restrained by lap belt alone despite the fact that forces on the seat belt were much lower.

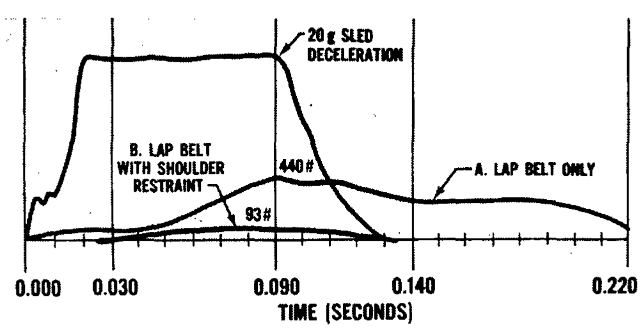

Fig. 8—Comparison of lap belt with lap belt plus shoulder restraint

This finding indicates that, insofar as the gravid uterus is concerned, in impact with any appreciable forces along the vertical body axis (as in the 0-45-0 position) strong increases in intrauterine pressures can be expected, even when the body is totally restrained from forward flexion. Whether such an increase is as deleterious to the fetus as that experienced when the uterus is impinged between belt and spine can only be determined through further studies comparing seat-belt-only with seat belt-plus-shoulder harness impacts.

Fetal demise occurring 1-2 hr after impact is difficult to explain. There were no gross injuries apparent to the fetuses at autopsy. The most likely cause of death would be maternal neurogenic shock. Our attempts to monitor maternal blood pressures were fraught with technical difficulties, but ausculatory methods were utilized post-impact on one occasion (Test 7) and hypotensive values were found. Studies are now in progress to remedy the instrumentation problem.

It is to be pointed out that placental separation, an expected finding, was not produced in any of the three pregnant animals impacted.

The finding of maternal post-impact bradycardia confirms earlier observations of this phenomenon by other workers (Refs. 6, 7). Its occurrence in the fetus, however, is an observation of extreme interest and one which may aid in determining the mechanism by which such bradycardia is produced.

Future runs will be concerned with answering the following questions:

1. Does maternal shock occur following abrupt deceleration? If so, what hypotensive levels are attained, and is this related to the death of the fetus?

2. At what level of decelerative force does placental separation occur?

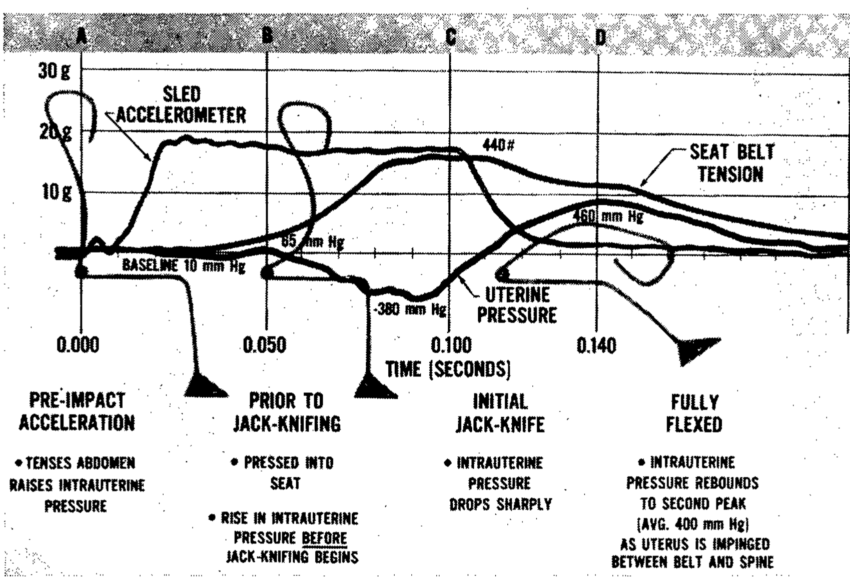

Fig. 9—Intrauterine pressure impact sequence

3. At what level of decelerative force does uterine rupture occur?
4. Can changes in the restraint system or seat position alter the survival rate of the fetus?

Summary

Preliminary data have been accumulated from a series of seven deceleration experiments on baboons. Three of these animals were pregnant, and, in two cases, fetal death occurred 1-2 hr after impact. (The third fetus and mother were sacrificed immediately after impact.) The cause of fetal demise has not yet been determined. It should be emphasized that the seat belt itself affords considerable protection to any pregnant occupant over non-use of a belt, and the authors do not wish to imply that the belts *per se* are dangerous.

Acknowledgment

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