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# I: EXPERIMENTAL STUDIES

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## I. Introduction

It is estimated that thousands of pregnant women are involved in vehicular accidents each year. Seat belts have been available for use by aircraft occupants for decades. With the current emphasis on safety, automobile occupants have also been urged to use lap-type seat belts. If the lap belt is worn, nearly all sudden decelerations will produce folding of the abdomen over the restraining belt. In minor accidents, this is usually of little consequence. But when the victim is pregnant, the resultant abdominal compression could produce uterine and fetal injury.[21] These experiments were undertaken to study the physical and physiological effects of impact on the pregnant animal with lap belt restraint.

## II. Method and Materials

The Savannah Baboon,** *Papio cynocephalus*, was chosen because the uterine and placental anatomy is similar to that of the human. The baboon breeds well in captivity and pregnancy can be accurately diagnosed and dated. The gestational period averages 167 days and the neonate weighs 750 to 1000 grams at birth.

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**The animals used for these experiments were lawfully acquired and treated in accordance with the Principles of Laboratory Animal Care issued by the Animal Facilities Standard Committee of the Animal Care Panel, U.S. Department of Health, Education, and Welfare, Public Health Service, March 1963.
Presented to Central Association of Obstetricians and Gynecologists in Detroit, Michigan, Sept. 14–16, 1967.

The Daisy Decelerator, an impact apparatus at the 6571st Aeromedical Laboratory, Holloman AFB, New Mexico, was used to produce deceleration. It consists of an air-driven piston that propels a sled along a track. The sled has a shaft protruding from the front that enters a brake. The brake resembles an engine block that is filled with water. A series of valves allows control of the rate of egress of water that has been displaced from the brake by entrance of the shaft. Sled velocity and rate of water exit from the brake control the degree and duration of decelerative force. A seat designed for the baboon was mounted on the sled. The seat was padded with 1″ Ensolite(R) on the floor and back.

Intrauterine pressures were measured either by an intra-amniotic Statham 222 pressure transducer or by a Microsystems 1017 pressure transducer in the wall of the uterus. Intra-abdominal pressure was measured with a Microsystems 1017 pressure transducer in the peritoneal cavity. Electrocardiograph leads of insulated stainless steel wires were sutured into the arm and the scalp of the fetus. Fetal heart rates were monitored by stethoscope when not recorded continuously by electrocardiography. The maternal electrocardiogram was obtained by Beckman silver-silver chloride adhesive electrodes. Maternal blood pressures were measured before and after impact by sphygmomanometer or through a polyethylene catheter in the abdominal aorta. The catheter had an internal diameter of 1.19 mm, and was connected to a Statham Series P23 pressure transducer. Aortic and hypogastric artery blood flow was measured by Biotronex Series 1000 electromagnetic flow transducers and recorded by means of Biotronex Model 310 flowmeters. Belt tensions were recorded by buckle-type strain gauges, designed and produced by the 6571st Aeromedical Laboratory. Instrument wires were connected to a cable attached to the sled and leading to the recording devices within the blockhouse. Physiologic data were recorded on a Sanborn Series 350 recorder. Physical data obtained during impact were recorded on a CEC Model 5–119 oscillographic recorder, with a paper speed of 63 inches/second. Photographic coverage was provided from anterior and lateral views by a high-speed camera. Serum electrolyte determinations were performed by a flame photometer. Total $CO_2$ content was determined by a Natelson microgasometer.

Three animals underwent hysterotomy with intra-amniotic placement of a pressure transducer and fetal electrocardiograph leads. Three animals underwent laparotomy with placement of a small pressure transducer within the uterine wall and a femoral arteriotomy. Three animals had femoral arteriotomy. In these 9 animals the surgical procedures were done on the day of impact. Two animals underwent thoracotomy and laparotomy with placement of electromagnetic flow transducers on the aortic arch and the hypogastric artery one week prior to impact. On the day of the experiment, the buried lead wires were exposed, and an intra-abdominal pressure transducer was placed. Following the surgical procedures, maternal electrocardiograph leads were attached, and the animal was carried to the sled and placed in the seat. The lap belt, of one inch wide 4500 lb. test woven nylon, was placed suprapubically at an angle of 55° from the horizontal, and adjusted to a tension of 1.5 kg. with a scale tensiometer. The shoulder harness consisted of a similar belt attached to the back of the chair above the right shoulder and to the seat behind the left hip. The legs were restrained by ankle straps attached to the undercarriage of the sled and the forearms were taped together to avoid interference with body motion during impact. The animal was allowed to recover from anesthesia to the point that it responded to stimuli and appeared fully awake (Fig. 1). The blood pressure transducer was removed from the sled and the animal decelerated. Following impact, the animal was monitored on the sled, on a stretcher, or in a restraint chair. The monitoring period varied from 20 minutes to 4 hours. If the fetal heart tones were lost at any time after impact, the animal was reanesthetized and delivered by Caesarian section (9 animals). One animal was sacrificed prior to fetal death (#2888), and one was delivered alive.

Anesthesia consisted of pentobarbital (1 animal), Innovar-Vet* (2 animals), or Sernyl** (8 animals). Ether was administered by open drop when necessary for abdominal surgery. Atropine and diphenylhydantoin were also used to supplement anesthesia. With the exception of pentobarbital, the drugs used did not seem to significantly alter physiologic responses to impact.

Eleven pregnant animals were used in 12 deceleration experiments. Eight underwent impact facing forward at 20 G with lap belt restraint. One of these (#3310) was first impacted at 20 G with lap belt and diagonal shoulder restraint ("3-point restraint"), and later in the day impacted at the same level with lap belt restraint alone (#3311). One had a single impact at 20 G with 3-point restraint (#3314). Two animals were impacted facing rearward, one at 40 G and the other at 20 G. These two animals were restrained by the 3-point system with additional adhesive tape used to keep the head firmly against the back of the seat during acceleration. One animal that died during the surgical procedure was impacted 2 hours after death facing forward at 33 G with lap belt restraint only. In addition, three pregnant control animals had similar surgical procedures without deceleration.

In nine experiments, the seat back was tilted at 20° to approximate the usual automobile situation, with the seat pan horizontal. In three experiments, the seat and seat pan were tilted backwards at an angle of 45° to simulate an aircraft accident.

## III. Results (Summarized in Tables I–VI)

Slow-motion photography shows that the upper torso of the animal continues moving forward following impact of the sled (Fig. 2). In animals impacted with a seat angle of 45°, the body initially compressed into the seat as the chest was thrown forward. Initial body compression did not occur when the seat pan was horizontal. In animals with lap belt restraint alone, the chest thrusts out and the head lags behind, producing hyper-extension of the cervical spine. By the time the upper torso is horizontal, the abdomen begins to impinge on the seat pan. The

*McNeil Laboratories, Inc., Fort Washington, Pa.
**Parke, Davis and Company, Detroit, Michigan.

abdomen flattens against the edge of the seat pan, and the chest continues moving downward until it hits the lower portion of the seat between the legs. The upper torso then rebounds upwards and backwards until it strikes the back of the seat, after which it falls off to one side and comes to rest. The entire sequence takes 0.5 to 0.75 seconds.

When restrained by the 3-point system, the chest impinges upon the diagonal strap and the shoulders move approximately 12″ from the back of the chair and then rebound back. In one animal (#3310) the diagonal strap was improperly placed across the right shoulder and upper left chest, without extending down across the abdomen. At impact, the upper torso underwent 180° rotation around the diagonal belt before returning to the normal seated position. *Rearward facing impact with 3-point restraint does not allow body flexion.* There is some motion however, with extension of the neck.

**A. Physical Data:** Intrauterine pressure begins to rise as the body compresses into the seat, producing an average initial peak of 500 mm Hg. Forward facing impact at 33 G with lap-belt restraint failed to exceed this maximum. In those animals impacted with a seat back angle of 20°, the initial peak of intrauterine pressure occurred at about the same time, but was lower and more prolonged. Regardless of seat angle, a second peak in intrauterine pressure occurred as the abdomen was compressed against the seat pan when the body was fully flexed. Average maximum pressure achieved during the second peak was 350 mm Hg. *With 3-point restraint or rearward facing impact, intrauterine pressure reached similar levels*, corresponding in time to compression of the body against the shoulder harness or the back of the seat. Intra-abdominal pressure reached a single maximum peak that occurred at full body flexion and approximated 50% of maximum intrauterine pressure.

Lap-belt tension rose to an average of 1050 lbs. following impact. Shoulder harness tension in those animals impacted facing forward with 3-point restraint rose to an average maximum of 800 lbs. With rearward facing impact, belt tension did not rise appreciably.

**B. Physiological Data:** Significant post-impact hypotension was observed in two animals, one related to pentobarbital anesthesia (#3062) and the other to a broad ligament hematoma (#3311). The maternal heart rate slowed an average of 50% immediately following impact in each animal in which the body underwent violent motion (Table I). Normal pre-impact heart rate was restored within 60 seconds. When forward flexion was prevented by 3-point restraint or rearward facing impact, maternal bradycardia did not occur (Table II).

The fetus invariably underwent post-impact bradycardia. In those animals in which there was flexion or torsion of the mother's body, there was a 50% decrease in the fetal heart rate (Table I), while in animals without body flexion, the decrease in the fetal heart rate was 21% (Table II). Two fetuses died during or immediately following impact (#3364, #3596), and two fetuses died prior to impact (#3317, #3592).

Serum electrolyte concentrations were measured in three animals (Table III). Blood was obtained from the femoral arterial catheter after surgery but before impact, and at intervals following impact. No severe alterations occurred. There was a moderate increase over pre-run values in hypogastric arterial flow in the one animal in which it could be calculated (#3592). Increased flow lasted for 20 minutes after impact and then returned to baseline. As yet, aortic flow measurements have not been calculated.

**C. Autopsy Findings** (Tables IV, V, VI): None of the adult animals died as a direct result of impact, but three had significant traumatic injuries. One had an extensive broad ligament hematoma, one had placental separation, and one had a subdural hemorrhage and placental separation. In another animal (#3592), partial separation of the placenta resulted in fetal death prior to impact. This was probably related to surgical implantation of a flow transducer on the hypogastric artery. Uterine rupture was not observed in these experiments.

None of the fetuses survived the experiment, and 3 of 11 sustained impact injuries. Two had cerebral hemorrhage and one had a depressed skull fracture with laceration of the underlying brain. One fetus was delivered alive by Caesarean section 1 hour after impact, but died 10 hours later of immaturity and atelectasis. Fetal death also occurred in the three control animals.

## IV. Discussion

These experiments were designed to produce an impact configuration comparable to an automobile accident, except for 3 in which the 45° seat angle simulated an airplane crash. Three-point restraint and rearward facing impact were added to provide comparative data in the absence of forward flexion. The 20-G configuration simulates a head-on collision at an impact of 40 miles per hour. Physical characteristics of many automobile accidents closely agree with those used in this study.[11] The injuries observed are similar to those reported in automobile accidents involving pregnant women.[7,20] No attempt was made to compare fetal survival between restraint systems because the number of available animals was small and because the surgical procedures resulted in fetal death in the absence of deceleration.

There is a remarkable increase in uterine pressure during impact. The maximum pressure observed was approximately 10 times that observed during labor.[19] Simultaneous recordings of abdominal pressure during impact show that the uterus was not protected from rupture by an equal but opposing pressure within the surrounding abdominal cavity.[18] Nor was there a decrease in uterine pressure during impact when forward flexion was prevented by shoulder restraint or rearward facing impact. The findings also indicate that the gravid uterus is capable of withstanding extraordinary pressures of short duration, and that such pressures are produced by deceleration with or without subsequent body flexion.

Maternal response to impact consisted of transient depression and bradycardia. The former resembled mild cerebral concussion. Post-impact bradycardia occurred only with violent motion of the body. Stapp and Taylor reported this phenomenon in deceleration experiments on human volunteers, and attributed it to increased vagal tone secondary to acute hypertension in the carotid sinus. This effect can be abolished by atropine, and occurs only when there is rapid forward motion of the head and neck.[22]

No fetus has yet survived an experiment. The apparent causes of fetal death are:

**A. Maternal Hypotension:** Two fetuses died in association with maternal shock (#3062, #3310–11). Elliot reported internal hemorrhage and resultant maternal shock as a major cause of both fetal and maternal death in unrestrained automobile accident victims.[7]

**B. Fetal Head Injury:** Two fetuses died with cerebral hemorrhage. One occurred with breech presentation and the fetal skull struck the maternal spine during rearward facing impact. In the other, the fetal skull was compressed between the seat pan and maternal spine. Fetal skull fracture was noted in another animal impacted after death. Many of the fetal head injuries reported in automobile accident victims have been associated with maternal pelvic fractures.[7,16] These experiments show that the maternal pelvis does not need to be fractured to produce injury to the fetal head during impact.

**C. Traumatic Separation of the Placenta:** Rapid compression and expansion of the uterus during impact may separate the placenta, and this may occur with or without body flexion. The shearing force may totally separate the placenta at the outset, or may initiate separation at the placental margin. Resultant bleeding produces a retroplacental hematoma that may ultimately separate the entire placenta and kill the fetus. Premature separation of the placenta has been observed following automobile accidents,[7,16,20] but there is some controversy as to how often it occurs. The incidence of trauma as a contributing factor ranges from 0 to 8% in published series.[3,13,15,17] The relative frequency of this complication in these experiments probably is more related to the superficial implantation of the baboon placenta than to the presence of the lap belt.

**D. Unknown Causes:** Three fetuses died without associated maternal or fetal injury. In addition, three control animals delivered stillborn infants within 48 hours of the operation. Since there was little change in serum electrolyte concentrations after surgery or impact, it is concluded that maternal acidosis was not a cause of fetal death in these experiments. Reduction of uterine blood flow also does not appear to be a contributing factor to post-impact fetal death in the absence of maternal shock.

The lap belt does not reduce the amount of force sustained in a collision, the force is merely transmitted to the pelvic structures. The head and chest are free to move forward or laterally, and the body jackknifes over the belt. The resultant abdominal compression could be expected to produce strain on the abdominal and pelvic organs. Injuries to the jejunum,[1,9,23] spleen,[2] colon, pancreas, and duodenum[25] have been attributed to the lap belt. These experiments show that fetal and placental injury may be produced when the victim is pregnant. Reports concerning injuries to pregnant automobile accident victims now are being collected by the authors. Twenty-one reports have been received and will be published subsequently. Such injuries have been infrequently reported;[4] their true incidence is unknown.

Studies of automobile accidents have shown that the major single cause of fatal injury is ejection from the vehicle.[12] When the body is ejected, injury occurs as it strikes the ground or is crushed by the vehicle. Restraining the occupant to prevent ejection should reduce fatal injuries. Tourin and Garrett state that, "seat belt restraint could save at least 5,000 lives a year and reduce injuries by ⅓".[24] Huelke and Gikas estimated that 80% of fatally injured automobile accident victims would have survived had they been wearing lap belts.[12] As a result of such studies, lap-type seat belts are now standard equipment on all new automobiles.[20] Reduction of fatal injuries has clearly justified their use.[5,6,8,10,12,14 24] Since ejection will occur whether or not the victim is pregnant, we believe that pregnant women should use lap belts for their own safety. The belt should be securely placed across the pelvis. It should not be worn over the fundus as this position may tend to increase abdominal compression during impact. It remains to be seen whether the fetus will be protected to a similar degree. The high rate of fetal and placental injury in these experimental studies indicates that additional restraint may be necessary to reduce the snubbing action of the lap belt.

## V. Summary

Eleven pregnant baboons were subjected to 12 experimental impacts. At the 20-G level of deceleration force, maternal injuries were minimal. Fetal death occurred in association with traumatic head injury, placental separation, and maternal shock. Although prevention of body flexion during impact did not prevent elevation of intrauterine pressure, fetal injury or placental separation; the number of animals is too small to draw conclusions regarding the superiority of one restraint system over another. The lap belt should be worn by pregnant women, and it should be securely placed across the pelvis and not over the fundus.

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# APPENDIX A

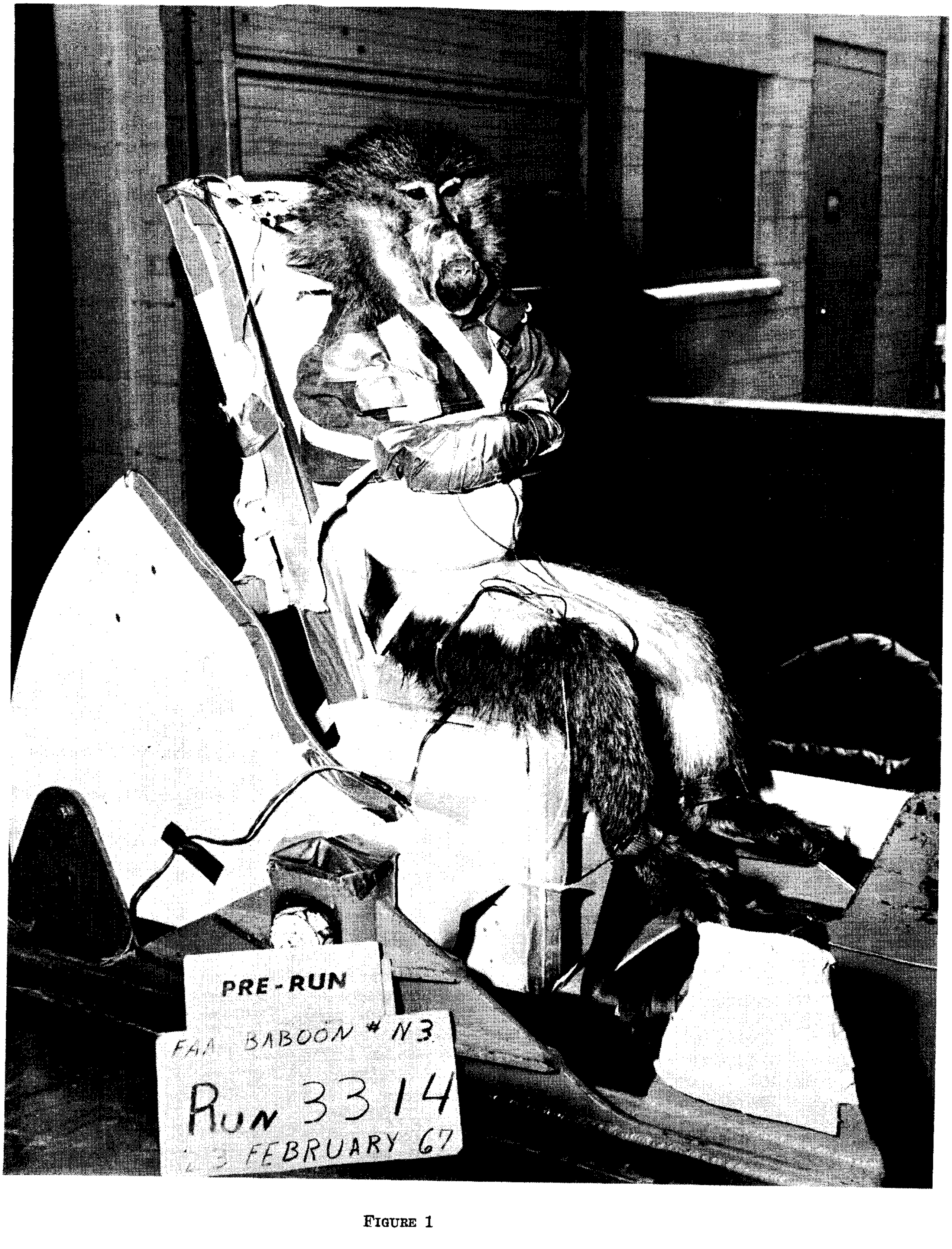


FIGURE 1

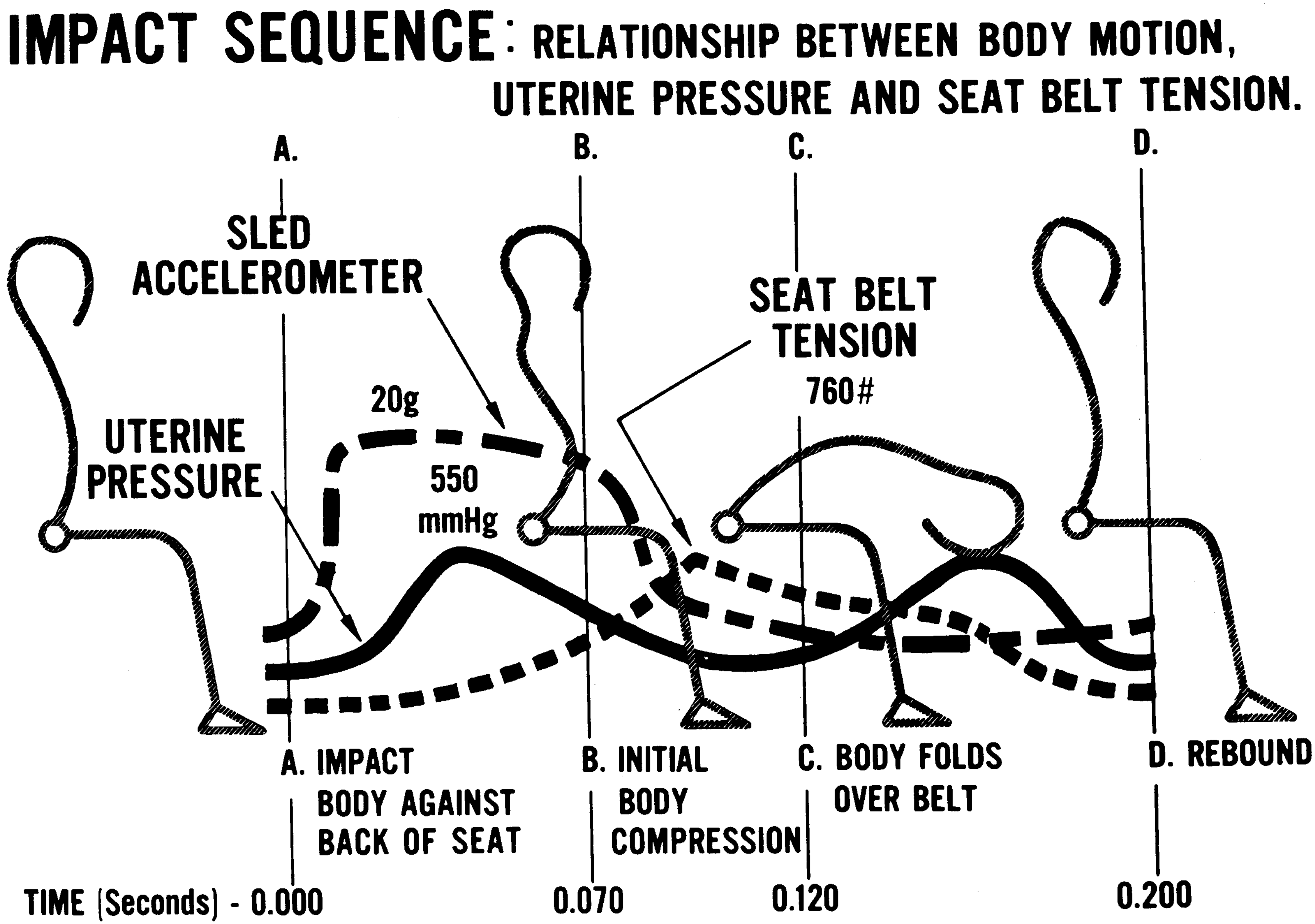
IMPACT SEQUENCE: RELATIONSHIP BETWEEN BODY MOTION, UTERINE PRESSURE AND SEAT BELT TENSION.
A.
B.
C.
D.
SLED ACCELEROMETER
SEAT BELT TENSION
760#
20g
UTERINE PRESSURE
550 mmHg
A. IMPACT BODY AGAINST BACK OF SEAT
B. INITIAL BODY COMPRESSION
C. BODY FOLDS OVER BELT
D. REBOUND
TIME (Seconds) - 0.000
0.070
0.120
0.200

FIGURE 2

# APPENDIX B

TABLE I. HEART RATE AND BLOOD PRESSURE FOLLOWING VIOLENT MOTION DURING FORWARD FACING IMPACT AT 20 G

| NUMBER | RESTRAINT | MATERNAL HEART RATE Pre-Run | Post Impact | MATERNAL BLOOD PRESSURE Pre-Run | Post Impact | FETAL HEART RATE Pre-Run | Post Impact |
|---|---|---|---|---|---|---|---|
| 2888 | Lap Belt | 130 | 36 | - | - | 135 | 60 |
| 3013 | Lap Belt | 170 | 85 | - | - | 150 | 40 |
| 3062 | Lap Belt | 150 | 90 | 135/95 | 90/60 | 160 | 80 |
| 3310 | 3-Point* | 175 | 90 | 165/100 | 140/100 | 180 | 110 |
| 3311 | Lap Belt | 140 | 55 | 165/110 | 100/65 | 124 | 70 |
| 3313 | Lap Belt | 170 | 105 | 160/105 | 160/100 | 170 | 92 |
| 3592 | Lap Belt | 220 | 98 | 90/80 (arm) | 100/60 (arm) | - | - |
| 3596 | Lap Belt | 234 | 180 | 110/80 | 90/70 | 170 | 0 (Died) |

*Animal underwent violent rotation around improperly placed diagonal shoulder strap.

TABLE II. HEART RATE AND BLOOD PRESSURE FOLLOWING IMPACT WITHOUT VIOLENT MOTION

| NUMBER | G | MATERNAL HEART RATE Pre-Run | Post Impact | MATERNAL BLOOD PRESSURE Pre-Run | Post Impact | FETAL HEART RATE Pre-Run | Post Impact |
|---|---|---|---|---|---|---|---|
| 3314 | 20 | 160 | 160 | 165/110 | 225/110 | 170 | 140 |
| 3364 | 40 | 230 | 210 | 150/100 | 160/110 | 110 | 0 (died) |
| 3365 | 20 | 160 | 160 | 135/65 | 130/75 | 160 | 124 |

TABLE III. SERUM CHEMISTRY

| NUMBER | TIME | Na(MEQ/L) | K(MEQ/L) | Cl(MEQ/L) | $CO_2$ (Vol %) |
|---|---|---|---|---|---|
| 3364 | Pre-Run | 159 | 3.8 | 130 | 45.9 |
| | +60 min | 159 | 3.8 | 126 | 38.3 |
| | +90 min | 157 | (hemolysed) | 127 | 43.8 |
| 3365 | Pre-Run | 150 | 3.6 | 121 | 39.0 |
| | +20 min | 146 | 3.9 | 117 | 37.8 |
| 3596 | Pre-Run | 147 | 4.5 | 112.5 | 44.5 |
| | +40 min | 143 | 4.8 | 110.5 | 41.9 |
| | +120 min | 143 | 4.8 | 110.8 | 44.0 |
| | +150 min | 151 | 5.7 | 110.3 | 43.5 |

TABLE IV. LAP BELT RESTRAINT: FORWARD FACING IMPACT AT 20 G*

| # | DAYS GESTATION | PRESENTATION | SEAT ANGLE | SURGICAL PROCEDURE | MATERNAL AUTOPSY | FETAL AUTOPSY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 2888 | 160 | Cephalic | 45° | Hysterotomy, FECG | 1/3 Placental Separation | No Trauma | Autopsy 20 min. post impact |
| 3013 | 140 | Cephalic | 45° | Hysterotomy, FECG | Living | No Trauma | |
| 3062 | 110 | Breech | 45° | Hysterotomy, FECG | Minor Trauma | No Trauma | Mother died in shock 24 hrs. post impact |
| 3311 | 154 | Cephalic | 20° | Laparotomy, Arteriotomy | Hematoma, Broad Ligament | No Trauma | Second impact of animal #3310 |
| 3313 | 166 | Cephalic | 20° | Arteriotomy | Minor Trauma | Cerebral Hemorrhage | Fetus died 11 min. post impact |
| 3592 | 103 | Cephalic | 20° | Thoracotomy, Laparotomy | 1/4 Placental Separation | Died Prior to Impact | Placental separation due to surgery, not impact |
| 3596 | 103 | Breech | 20° | Thoracotomy, Laparotomy, Arteriotomy | Minor Trauma (Aspiration) | No Trauma | Mother died 18 hrs. post impact of aspiration |

*Animal #3317 not included in these tables. It was impacted after death, forward facing at 33 G with lap restraint. The dead fetus was in breech presentation and sustained a depressed skull fracture and brain laceration.

TABLE V. 3-POINT RESTRAINT: FORWARD FACING IMPACT AT 20 G

| # | DAYS GESTATION | PRESENTATION | SEAT ANGLE | SURGICAL PROCEDURE | MATERNAL AUTOPSY | FETAL AUTOPSY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 3310* | 154 | Cephalic | 20° | Laparotomy, Arteriotomy | Hematoma, Broad Ligament | No Trauma | Animal rotated around shoulder strap. |
| 3314 | 153 | Cephalic | 20° | Arteriotomy | Minor Trauma | No Trauma | Fetus born alive, died of prematurity. |

*Animal impacted 2 hours later with lap restraint (#3311).

TABLE VI. REARWARD FACING IMPACT, 3-POINT RESTRAINT

| # | DAYS GESTATION | PRESENTATION | SEAT ANGLE | SURGICAL PROCEDURE | MATERNAL AUTOPSY | FETAL AUTOPSY | COMMENTS |
|---|---|---|---|---|---|---|---|
| 3364 | 145 | Breech | 20° | Laparotomy, Arteriotomy | Subdural Hemm. Placental Separation | Cerebral Hemorrhage | 40 G Impact |
| 3365 | 110 | Breech | 20° | Arteriotomy | Minor Trauma | No Trauma | 20 G Impact |

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