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PATHOLOGY OF TRAUMA ATTRIBUTED TO RESTRAINT SYSTEMS IN CRASH IMPACTS

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I. Introduction

Although restraint systems have been used for over 50 years in military aircraft, and in some form for about 113 years in lighter-than-air types of vehicles, their use in other forms of transportation has been relatively new. Such systems have conclusively demonstrated their overall protective value to vehicle occupants; however, experimental evaluation of the various systems is necessary for the design of improved future systems, as well as for developing even better protective use of present systems. In recent years considerable attention has been focused on the more sophisticated military restraint systems, and in particular on the protection of rather specialized occupants of space vehicles. Injuries reported in the past have primarily related to problems of high-speed ejection (vertical $\pm G_z$) decelerations involving vertebral trauma, isolated clinical findings, or to by-products of experimental studies involving other basic objectives.

Very little attention has been given to the type and severity of injuries which may be attributed to the vast majority of restraint systems more generally used. Commercial airline transports currently utilize only lap belts for passenger protection as do almost all general aviation aircraft in the United States, military troop transports, and military helicopter transports. Even such advanced aircraft as the 350–passenger Boeing SST, the 750–passenger Lockheed C5A, and the 490–passenger Boeing 747 will have only the lap-belt system in all but aircrew cockpit positions. In addition, similar systems are now being installed in some 8.5 million automotive vehicles per year. Pilot populations such as the Apollo astronauts, airline transport and military pilots represent very select young male physical types, and their restraint needs and injury tolerances may differ considerably from those of the general population which include infants and children, women, and the aged and infirm.

The work reported here was conducted on the USAF 6571st Aeromedical Research Laboratory Daisy Decelerator as a project of the Protection and Survival Laboratory, Civil Aeromedical Institute (CAMI), Federal Aviation Administration. These studies involved a series of related investigations assessing the protection from impact trauma provided by various restraint systems commonly found in aircraft and automotive vehicles. The latter phases of this series also included two experimental systems.

The initial project was designed to investigate injury to the pregnant female and/or fetus due to lap belt forces at impact. This question has had some discussion, but very little clinical data are available,[52] and no prior experimental study has been conducted. The deceleration patterns selected for this study were based upon the hypothetical situation of a pregnant woman passenger subjected to the impact forces of a specific type of airline jet transport, at 175,000 lbs. gross weight, crash landing after losing power on one engine at 200 feet altitude after takeoff (45° body orientation, forward facing, 39g., 260 ft./sec. impact velocity, and 0.125 seconds duration of initial impact). The passenger was assumed to be located in the first row of the first-class section. Since this condition proved to be non-survivable for the first experimental baboon subject protected by lap belt only, subsequent tests were conducted at lower levels for this system,

The work reported in this study was supported by the Civil Aeromedical Institute, Federal Aviation Administration, Department of Transportation, Oklahoma City, utilizing the facilities and cooperation of the 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico. The opinions expressed are those of the authors and do not necessarily reflect the official viewpoints of the several organizations concerned.

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 Standards Committee of the Animal Care Panel, U.S. Department of Health, Education, and Welfare, Public Health Service, March, 1963.

and included patterns simulating exposures in forward- and rear-facing seats in aircraft as well as automotive impacts.[58,61] The preliminary work in which 11 pregnant baboons were subjected to 12 experimental impacts, indicated that at 20g. maternal trauma was minimal, but fetal death occurred in association with fetal head injury, placental separation, and maternal shock.[15]

In response to requests by the Society of Automotive Engineers S–9 Committee and the Steward and Stewardess Division of the Air Line Pilots Association, a second test series examined the problem of lap belt only restraint protection for aircraft occupants in lateral seating positions such as lounge, aircrew, or stewardess station. Twenty-four deceleration tests were performed on 24 adult female baboons, in controlled experiments comparing sideward, rearward, and forward impact effects. Impact levels causing injury to the baboon subjects in 14 lateral orientations were determined to be much lower than in either rearward- or forward-facing body orientations, with fatal injuries occurring as low as 16.5g. when the occupant wore a lap belt only.[59]

A final test series compared two types of experimental systems, the inverted-Y yoke with inertia reel and the airbag restraint system.[60] In addition, forward, rearward, and sideward tests were made of other systems currently in use, such as the 3-point (lap belt-diagonal belt system) and the diagonal only restraint system favored in some European automotive vehicles.

The entire series of related studies of restraint protection and impact injuries using baboon subjects has been brought together in this paper to present an overall view of trauma sustained by the occupant restrained by the systems evaluated.

II. Methods and Materials

Sixty-two deceleration tests were performed on 59 adult female Savannah baboons *(Papio cynocephalus)**, ranging in body weight from 15.5 to 36 pounds (9.5 to 16.3 kg.). Age estimates based on dental examination ranged from 4½ to 12 years (CS).

The tests of this series were conducted on the Daisy Decelerator between 23 May 1966, and 3 June 1967.[12] Several sled and seat combinations were used, depending upon the particular profile run. All seats were scaled down proportionately for the baboon, and as noted in Table I, the F–111 test frame, mounted on the ARL Omni-Directional sled was used for most of the tests. The 4,500-pound tensile test nylon webbing used in each test was replaced after each run; lap belt angle was 55° to the plane of the seat pan. Prior to each run, static belt tension for each side was stabilized at 1.5 kg. (3.3 lb.).

Subject orientations (presented in Table I) were 90° sideward facing (45° seat pitch), 50° sideward facing (13° and 20° seat pitch), forward facing (13°, 20°, and 45° seat pitch), and rearward facing (13° and 20° seat pitch) body orientations.

Time duration varied from 0.059—0.121 second, the latter being the longest duration at 30g. the Daisy track was capable of providing safely with this sled load. Entrance velocities varied from 36.4 ft./sec. to 94.4 ft./sec., rate of onset from 1,200 to 6,800 g./sec., and peak sled forces from 15g. to 57g. Figure 1 diagrams the configuration of the various restraint systems used. Since the air-bag and inverted-Y yoke systems were experimental, a brief additional description for these follows: The air-bag restraint for the baboons was scaled down to be of the same relative size as the full-size version for the humans previously tested with anthropomorphic dummies for automotive use. Each bag was folded into a test instrument panel 10″ forward of the seated baboon (Fig. 1–F). Bag inflation was initiated by electronic impulse as the sled probe penetrated the brake system at impact. As the subject came into contact with the bag during impact, the bag was deflated through pressure relief diaphragms on either side. This produced a dynamic system with deflation occurring as the occupant moved into the restraint during the impact sequence. Air bag tests were designed as paired tests, from 30g. to 50g. (avg. g., sled acceleration), with one animal terminated immediately post-impact (3–6 minutes), and the second animal for each g-level allowed to survive for chronic post-impact monitoring. Two of the latter were monitored for 4 weeks (and one for 12 weeks) to allow any possible trauma as a result of impact to become evident.

The upper torso inverted-Y yoke restraint system consisted of a single lap belt with an experimental upper torso harness. Strain gauges were mounted on both sides of the lap belt to record belt forces. The upper torso portion of

*Previously designated by primatologists as Kenya Baboon (*Papio doguera*).

the harness attached separately at each side adjacent to the lap belt tie-downs, and was also equipped with strain gauges (Fig. 1–E). The yoke of the harness was formed at the posterior aspect of the head, but did not touch the head or neck. It provided some rearward motion protection, but we did not test to what degree it could offer protection from hyper-extension in rear impacts. The harness, continuing as a single belt from the yoke, was attached overhead at a 45° shoulder angle (relative to the horizontal plane) into the inertia reel, which was activated at 0.3g. For the inverted-Y yoke system tests protocol was established for one run at 30g. (sled X, avg. g.) in both forward-facing and side-facing positions, one run at 43g., and one run at 49g. An initial value of 30g. was selected because this was the level at which lethal impact injury occurred in about 50% of the animals when impacted with lap belt only restraint systems. Sled g. was chosen as a measure since this could be accurately determined and compared to previous tests. Subject decelerations had proven to be extremely unreliable in previous tests due to problems of orientation and mounting procedures.

The seat was padded with 1-inch Ensolite on the back and seat. No physiological measures were made in 50 tests to reduce chances of surgical artifacts. In another 12 tests, involving pregnant animals, physiological monitoring consisted of the following: intra-abdominal pressure was measured in the peritoneal cavity with a Micro-systems 1017 pressure transducer implanted in the wall of the uterus or by an intra-amniotic Statham 222 pressure transducer.

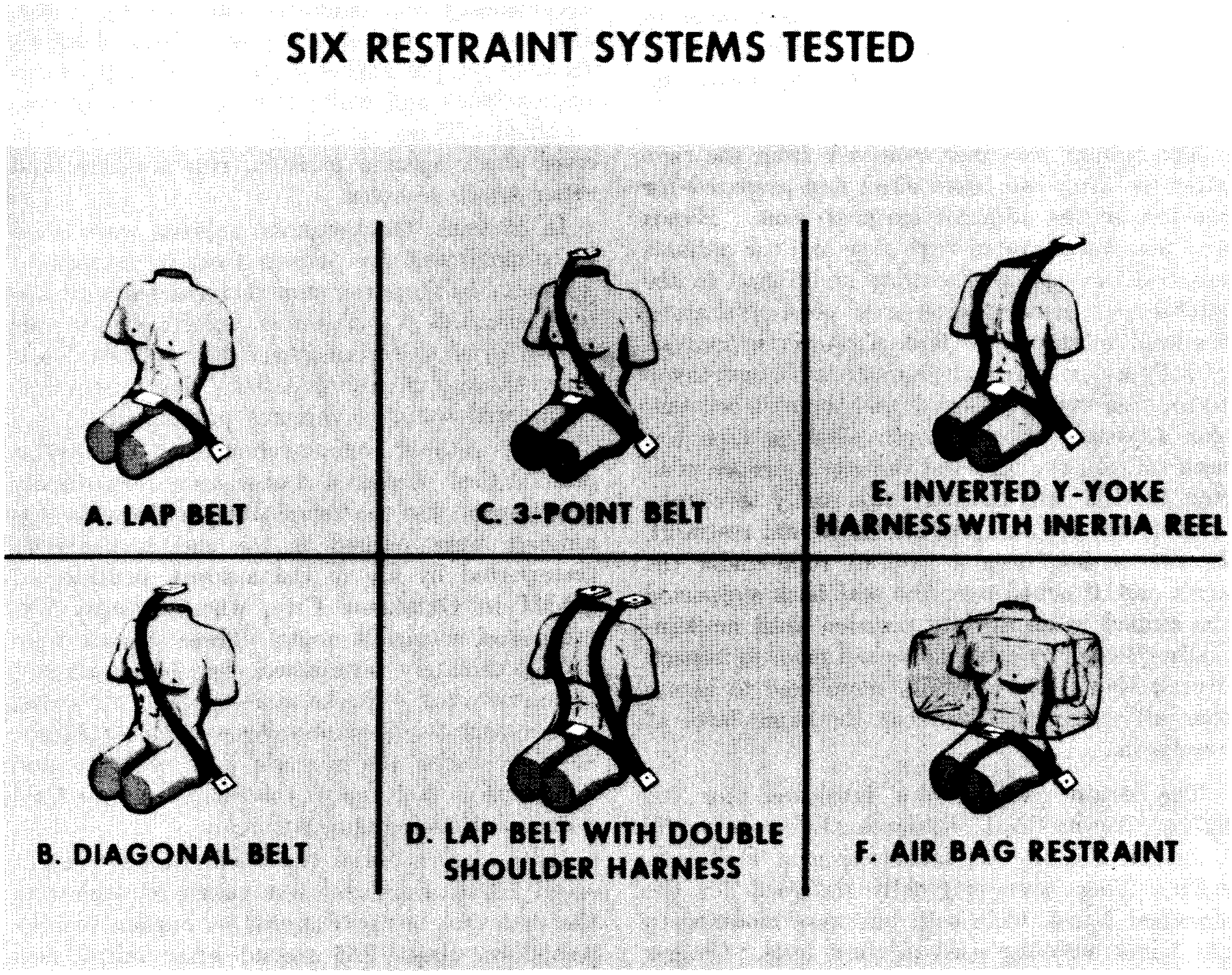

FIGURE 1. The six types of restraint systems tested.

Maternal blood pressures were recorded pre- and post-impact by sphygmomanometer or through a trans-femoral catheter in the abdominal aorta, connected to a Statham P–23 pressure transducer. Maternal electrocardiograms were obtained with Beckman silver-silver chloride adhesive electrodes. Fetal electrocardiograph leads of insulated stainless steel wires were inserted into the scalp and arm of the fetus. Fetal heart rates were monitored by stethoscope and/or recorded continuously by electrocardiography. Serum electrolyte determinations and arterial CO_2 for 13 pregnant animals were determined. For details of blood chemistry technique for each case the reader is referred to Crosby.[15]

Each subject was anesthetized with 1 mg./1 kg. body weight Sernalyn (R) prior to each run. I-V Nembutal (R) was used on one animal and Innovar-vet(R) on two animals. Ether, atropine, and diphenylhydantoin were also used prior to surgery in the pregnant series. These drugs did not appear to significantly alter physiologic responses to impact.

The subject was then removed from the cage after the drug had taken effect and prepared for the test in the adjacent surgical room. Hands and feet were covered with tape and the animals muzzled in order to facilitate handling. In the lateral tests, 1-inch targets were positioned along the head and trunk for later photometric analysis of body kinematics. The animals were next taken to the test sled, positioned, and the seat belt tension adjusted. Low-strength masking tape was used to keep the legs and thorax in proper position for the run; however, this easily tore upon impact and did not provide additional restraint. In the air-bag tests a loop of rope under the arms and attached over the seat back supported the animal in an upright position until mechanically released by cable 0.6 second prior to impact. Muscle tonus was carefully monitored to assure that all runs were made at the same level of anesthesia.

The strain gauges were fabricated for the 6571st Aeromedical Research Laboratory by Land-Air Division of Dynalectron at Holloman AFB. They were originally designed for the standard 2-inch wide belt, but were modified to the 1-inch webbing used in these tests. Gauges were placed at each end of the belt; two were used for lap belts and four gauges for the other systems. Each strain gauge buckle was instrumented with four strain gauges to measure the bending moment due to the force imposed on the belt. Although each buckle contained eight elements, it electrically appeared as a four-active-arm bridge. When the belt was stretched, the metal of the buckle was stressed and deflected. Resistance of the electrical elements changed as a result of changes of strain on the metal. Calibrations were made by placing a known force on the belt and measuring the electrical output of the bridge.

Photographic coverage included use of a Waddel 16–1A 2,000 fps camera for frontal view, and one or two Ippolito Fastex 2,000 fps cameras for lateral views. In some runs, film from one of the lateral views was processed immediately and wet-viewed to examine results of each test quickly prior to the succeeding tests; 16 mm. documentary color film, 35 mm. still color film, and 4x5 still photography were also obtained. In addition, pre-impact, during impact, and post-impact black and white Polaroid (R) photos were obtained. These served as useful references to cross check specific position, run numbers, and other details of notes.

In 12 runs, the pregnant animals were clinically monitored for periods from 20 minutes to 4 hours. In the seven animals impacted with air-bag restraints a post-impact blood sample was drawn prior to termination (5–20 minutes post-impact), and in all the others the animal was terminated within 5 minutes post-impact.

Gross autopsy was conducted at the 6571st Aeromedical Research Laboratory immediately post-impact for the terminated subjects, or the animals were packed in ice and immediately transported by air to the autopsy facilities of CAMI in Oklahoma City, where autopsy was completed within 24 hours. Three animals were not immediately terminated, two being allowed to survive for 4 weeks, and one for 12 weeks, post-impact to determine chronic impact effects. In these cases, the animals were observed and autopsied at facilities of the Space/Defense Corporation, Birmingham, Michigan.

In the lateral series two Field Emission high-speed roentgenograms were taken of each run, the first shot being triggered at impact and the second at about 0.65 second after initial sled entry into the brake; however, none of these proved useful. Whole body post-impact anterior-posterior and lateral view radiographic studies were made prior to autopsy. Gross and microscopic tissue study of the brain was complemented by electronmicroscopy examination for fibrinolytic activity. Blood analyses were conducted in a search for biochemical indicators of impact stress and/or tissue damage. Blood samples for these analyses were taken for the seven air-bag subjects prior to impact, immediately post-impact, and for the three animals observed for 1–3 months post-impact, at 7-day intervals for one month. The hematology is summarized in Snyder, et al.[61] Specific techniques employed are those provided in detail by Life.[45]

III. Results and Discussion

In each restraint system tested in this series, injuries to occupants were found which could be attributed to the system itself. The patterns of trauma were found to differ in each case as a function of the type of restraint and the body kinematic action during impact. Additional variables found to be of importance included magnitude, onset rate, velocity, and time duration of impact, distribution of force upon the body, and direction of force (body orientation to the impact). Variables not studied, but also believed to be of importance would include the age, sex, and physical condition of the restrained subject.

This series of tests provide a basis for the assessment of traumatic and protective qualities of these restraint systems for the baboon subject. The confidence with which results observed on the baboon may be extrapolated to the human is reinforced by the fact that the injuries found in these tests are similar to those which have been reported for human subjects in accidents involving similar restraint systems. Such an experimental approach testing living systems is a necessary corollary to studies based on the use of cadavers or anthropomorphic dummies.

Tables I–VI (Appendix A) provide the results of gross and microscopic pathology and note the individual conditions for each test, a summary of the physical data, and records of peak belt forces. Our findings for each system will be briefly discussed here, but for further detail refer to these tables.

A. ***Lap Belt Only.*** Lap belt refers to a single belt worn across the anterior aspect of the pelvic structure (Fig. 1–A). Properly worn, this restrains the body by its strongest structural elements and reasonably close to the total body center of gravity. It prevents ejection, which has been demonstrated to be the major single cause of fatal injury in automotive type accidents;[37] however, in forward or lateral impact it offers no upper body support, thus head and thorax are free to "jackknife" over the lap belt.

The lap belt restraint is the most commonly used system for both aircraft and automotive occupants. Its effectiveness has been well documented by many investigators, their studies indicating that the lap belt alone can reduce injuries by substantial amounts.[35,47,71] Huelke and Gikas found in their study of fatal accidents that "of 48 ejectees, 38, or 80 percent, would have survived if they had been wearing only the lap seat belt."[37] Nevertheless, as Fish & Wright[24] have recently noted, this device can in itself be responsible for distinctive injury patterns. Injury to the jejunum,[1,29,43,71] spleen,[14] pancreas,[28,77] duodenum,[77] ileum,[42] and abdominal hernia[43] has been attributed directly to the lap belt. In addition, lumbar compression fractures have been reported since the body hyper-extends over the belt,[28,38,54,61] as well as transverse fracture of the vertebral body[36] attributed to the high placement of the lap belt which allowed the belt to act as a fulcrum, literally "splitting apart" the vertebral body. A "splitting fracture" of the pedicles, transverse processes, and lamina of the third lumbar vertebra has been reported.[26] Smith and Kaufer have recently reported finding 10 of 17 cases of spine injuries from seat belts, involving a tension-type fracture to the lumbar vertebrae.[55] In pregnant women traumatic rupture of the uterus,[15,24,52] ventral hernia,[38] and placental separation[16] have been reported.

Teare's findings of abdominal and thoracic aortic ruptures, attributed to the jackknifing of occupants over the lap belt during a 1951 Comet jet airliner crash in England,[68] the report of DuBois of 23 cases of intra-abdominal trauma and 32 cases of contusions in 858 aircraft accidents in 1952,[20] and that of DeHaven, *et al*[19] in which they attributed only bruises due to the belt to 1,029 survivors of 670 light aircraft accidents, were early efforts at investigating this problem. Lap belts are being worn more by larger numbers of individuals as airline travel becomes more common, and because all new automobiles manufactured in the U.S. are required to have belts installed. Thus, it should not be surprising to note that there has recently been a sharp increase in the incidence of trauma attributed to the seat belt, reflected in the more than 20 clinical reports in the literature concerned with this problem since 1961.[57]

Forward-facing lap belt impacts were conducted in 18 of the 36 lap belt tests (Table I–A). Of these, five were impacted with seat pitch attitude of 45° to simulate a jet airliner crash, while two were at 13° and 11 at 20° to simulate seating profile in a level aircraft or automotive accident. Entrance velocities ranged from 38.2 to 87 ft./sec., onset rates from 1,400 to 6,800 g./sec., time durations from 0.050 to 0.080 second, and magnitude from 16.5 to 40g.

In all cases, transverse linear contusions of the anterior abdominal wall corresponded to the position of the belt at impact (Fig. 2). It is suggested that a careful examination for such bruising be routinely made in human accident victims as it may serve as a valuable sign of more serious intra-abdominal injury. Up to approximately 25g., congestion and/or minimal hemorrhages were noted in the brain, spleen, heart, uterus, and pancreas. In general, however, the pathology appeared to be reversible and compatible with recovery. Above 25g., injury was more severe and along with damage to the previously mentioned organs, ruptured urinary bladders, pulmonary lacerations and interstitial and pericapsular renal hemorrhages were increasingly frequent. Beyond 30g. survival could be considered marginal and beyond 40g., the impacts were definitely lethal.

Since previous clinical reports have suggested that incorrect wearing (loose, high) of the lap belt may have contributed to the injuries,[14,29,38,43,58,61,77] an attempt was made to duplicate this factor in three runs. While this did appear to result in more extensive injury in one case at 30g. (3372), it was inconclusive for two other tests at 34g. (3315) and 40g. (2880).

Previous human tests by Lewis and Stapp with healthy, young male subjects resulted in complaints of abdominal pain at 15–20g.[44] Minimal contusions over the hip area and abdomen as well as strain of the anterior abdominal musculature

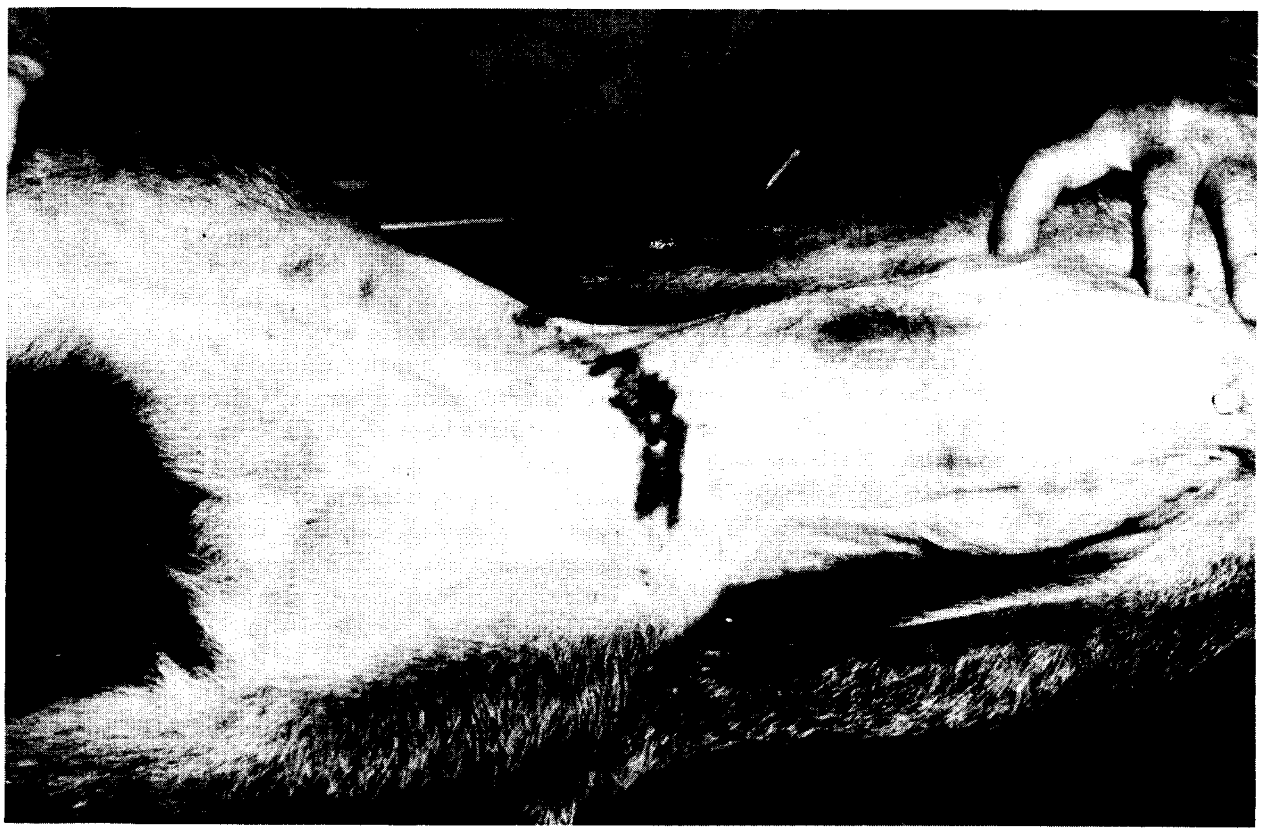

FIGURE 2. Typical contusion resulting from impingement of lap belt in impact.

FIGURE 3. Baboon positioned in seat on omni-directional sled prior to impact run in lateral body position. Note photometric locators on animal and along portion of seat back.

due to lap belt impingement were found to occur at 10g. (300 g./sec., 0.002 sec.). In one 26g. impact (the highest lap-belt-only experimental test run on humans), the subject complained of severe epigastric pain persisting for 30 seconds and thoracic pain for 48 hours. Seat belt forces of 4,290 pounds, and an average impingement force of 89.3 psi over the belt area were calculated.[44,64,65] Subsequent tests on the Daisy track have not exceeded 15g., until recent tests of 17g. by the National Bureau of Standards,[3] considered to be the upper limit of subjective tolerable impact with a lap belt system in forward impact.

Forward, as well as rearward, lap-belt-only impact for pregnant baboons at 20g. resulted in fetal demise, even when the mother was not significantly injured. Death to the fetus occurred in association with placental separation, traumatic head injury, and maternal shock.[15]

Fourteen tests with lap-belt-restrained subjects impacted in the 90° sideward facing body position (Fig. 3) resulted in injuries surprising in their extent (Table I–B).[59] In this series, sled entrance velocities ranged from 36.4 to 75 ft./sec., 15 to 31g., and 1,200 to 3,100 g./sec. onset rates. Since all animals were terminated post-impact, survival must be judged from the trauma found upon autopsy, and it seems probable that without immediate and extensive medical assistance only the 15g. impact would have been survived. It is interesting to note that human voluntary lateral subjective tolerance levels have been found to be about 9g. (Zaborowski),[84] much lower than for either forward- or rearward-facing positions. Five animals received ruptured bladders (which did not occur in forward or rearward lap belt impacts). Contusions, tears or lacerations, and one complete severance of the uterus also occurred in five cases. In three instances, cervical frac-

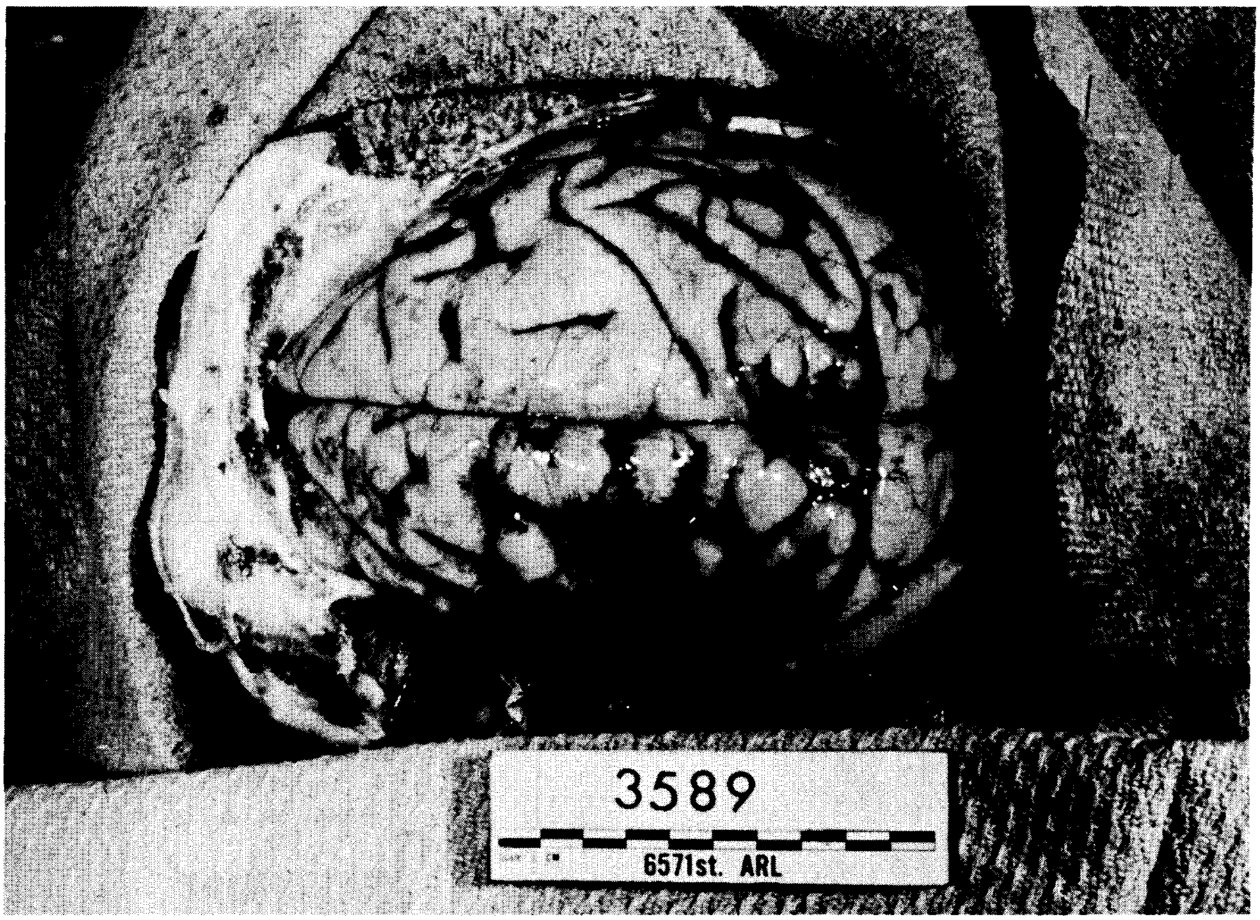

FIGURE 4. Subdural hemorrhage in baboon impacted forward facing, lap belt only, at 32g. and 75 ft./sec. velocity. A high frequency of dural congestion and hemorrhage was found.

tures occurred with complete atlanto-occipital separation. Transection of the spinal cord occurred in one 30g. impact. Again, such cervical trauma did not occur in either forward or rearward lap belt tests. The most significant finding was that of pancreatic hemorrhage in all lateral cases which were autopsied. Intra-cranial hemorrhage was again noted in each case (Fig. 4). Inter-acinar hemorrhage, typical of these lateral impacts, is shown in Figure 5. Although such trauma has not been reported by previous investigators, even in tests with humans exposed to 22g. and a bear to 46g.,[13] such tests have been conducted with full body restraint and not lap belt alone, as in these tests.

To clarify the role of post-mortem pancreatic degeneration, one baboon was terminated without being impacted, and treated in the same manner as those in the impact series. After termination with Nembutal (R), the cadaver was held at room temperature for 1.5 hours and then packed in ice in a shipping container. A temperature probe was inserted inferior to the right lobe of the liver and recordings kept. Body temperature of 96.8°F. dropped to 96.2°F. after 1.5 hours, to 64.8°F. within 14 hours, and to 48°F. within 24 hours. After 24 hours, gross necropsy and histopathologic examination revealed mild pancreatic necrosis without pancreatic hemorrhage. This indicated that part of the necrosis observed during necropsy was due to post-mortem changes in the pancreas, but since associated hemorrhagic findings occurred only in pancreases of impacted

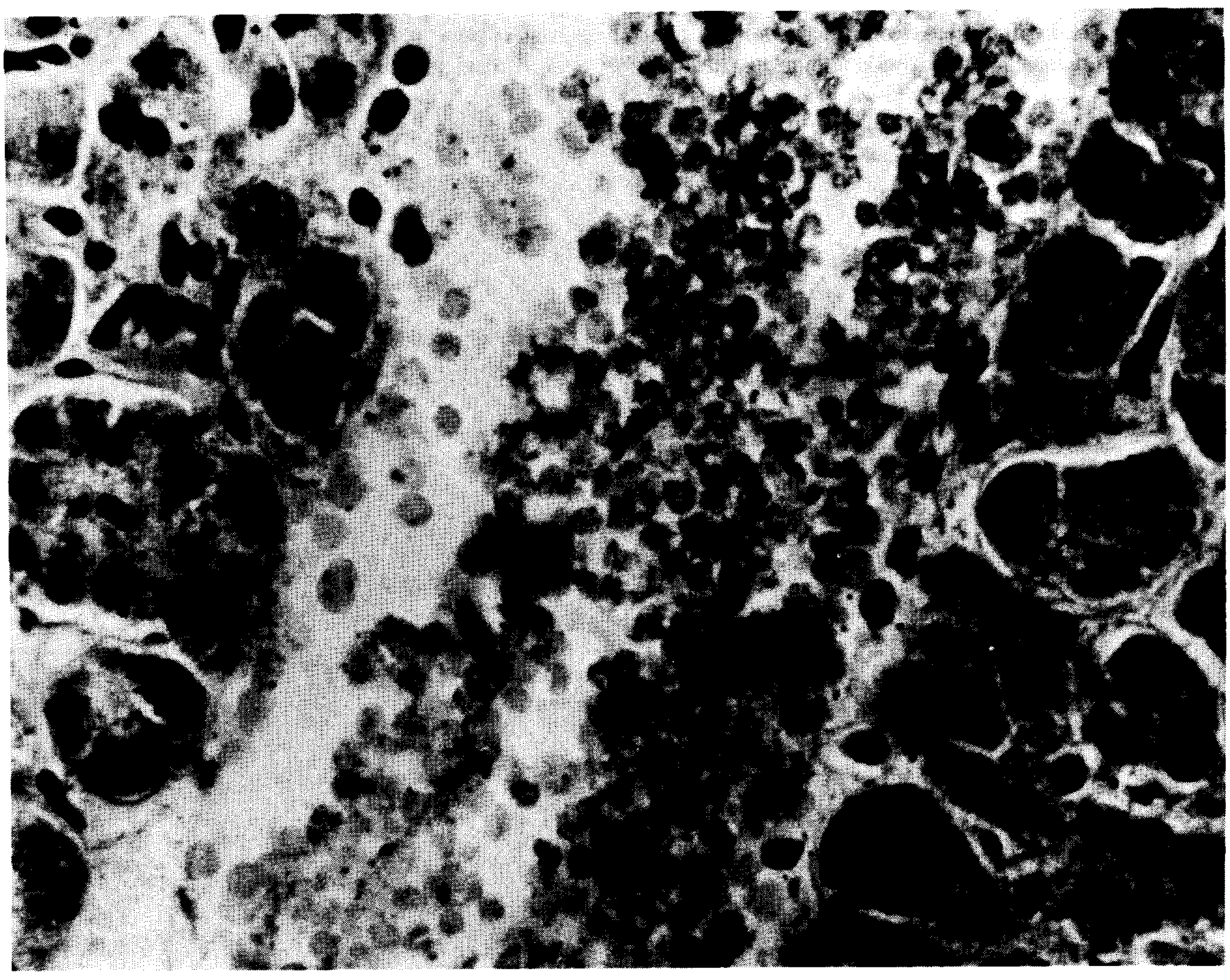

FIGURE 5. Inter-acinar hemorrhage of pancreas typical of lateral baboon impacts at every level tested at and above 16.5g.

animals, they were considered to be a direct result of the trauma.

The significance of the inter-acinar hemorrhages observed in the pancreas at necropsy following impact is unexpected and has been carefully considered. Previous descriptions of pancreatic injury have been related to dietary excesses, direct trauma resulting from blows over the left upper quadrant of the abdomen, surgical trauma, and reflux from the intestine,[17,33,34-39,41,51,66,69,74,75,78,81] but we have not found similar reports of pancreatic injury related to sudden, violent compression and/or displacement of the viscera such as we found in this series of experiments. Immediately after impact, we observed retroperitoneal and intralobular hemorrhage grossly and inter-acinar hemorrhage histologically. It is clear that there have been intra-abdominal forces sufficient to rupture the capillary bed. It is not unreasonable to believe that these same forces could break the more delicate radicles of the intralobular ducts which are formed only by the centroacinous cells with the release and activation of pancreatic enzymes. However, this must still remain speculation until proven or disproven by clinical study of survivors.

Recent work suggests that the pancreatic hemorrhage may be more critical in the baboon than in man since recent studies[2] indicate that the output of serum amylase and lipase is several fold higher in the baboon than in the human. Hence, mechanical disruption of the duct system with consequent release of enzyme might be expected to result in a far more fulminating outcome in baboons than in humans.

Rearward-facing body orientations (Table I–C) at impact were used in four cases, all at 20° pitch attitude. These ranged from 22 to 44g., 59 to 88 ft./sec. velocity, 2,300 to 5,850 g./sec. onset rates, and 76 to 100 milliseconds time duration. Seat belt forces of 30–120 pounds

FIGURE 6. Subperitoneal hemorrhage in pancreas resulting from subject's impingement upon single diagonal belt only.

were recorded, upon rebound, since the force was distributed upon the subject's back rather than being concentrated at the harness, as in forward-facing impacts. All runs were survived without significant trauma. At 44g., extensive abdominal bruising was the only injury which could be directly attributed to the restraint. Despite findings of intra-cranial hemorrhage in three of the four cases, these injuries were considered reversible (with the exception of the fetal death). The rearward-facing body orientation offered the best support in impact for the lap-belt-only restrained subject.

B. *Diagonal Belt Tests.* Tests with the single diagonal belt only (Fig. 1–B) were made because this restraint system has been reported used in as much as 85% of Swedish automobiles.[4] This system extends across the shoulder and chest on the outboard side (left shoulder for driver, right shoulder for passenger) diagonally across the chest to the opposite hip, where it is anchored to the floor. In our tests, the subjects received fatal trauma. This system not only does not provide pelvic restraint, which allows the subject's lower torso to swing forward and rotate out of the belt at impact (unless stopped by striking the instrument panel, car door, or other structure), but in side impact produces an extremely lethal whipping action in which the body literally rotates about and out of the belt. There have been several studies of injuries attributed to this type of belt—including data on chest injuries,[4,6,9,47,48,77] as well as ruptured spleen,[32] and sternal fracture.[26]

In our series, two forward-facing 30g. tests and one sideward-facing 30g. test were run (Table II, A and B). As can be readily seen from the severe trauma received in each case, this "restraint" system certainly does not appear to offer many advantages, and cannot be considered equal in protective capability to the lap belt. In each case, massive destruction of the thoracic cage occurred, with extensive avulsion and rupture of the pectoral muscles, numerous rib fractures,

FIGURE 7. Lacerations of liver typical of trauma in impacted subjects protected by a single diagonal belt only.

and trauma to the kidney (Fig. 6), liver (Fig. 7), spleen, pericardium, lungs, pancreas (Fig. 8), adrenals, rupture or hemorrhage of the sigmoid colon, and dural hemorrhage. Diagonal linear contusions from belt impingement were marked. Among other findings, it is interesting to note that myofibrillar degeneration was observed in two of the animals during microscopic examination of myocardial tissue (Figs. 9, 10). A similar observation was noted in one 22g. side-facing, 3-point belt impact, one 49g. forward, yoke-restraint impact, and to date, in four animals subjected to vertical drops in a current series by Snow.[56] Fragmentation of the myocardial fibres and whether it represents decelerative, traumatic rupture of the heart as described by Moritz and Atkins,[50] a processing artifact, or whether the heart is in systole or diastole at the time of impact, has been discussed by Mason.[49] It should be noted that an experimental study of chest impact recently completed by Life and Pince[46] has conclusively demonstrated that severity of cardiac trauma in canine impact is directly related to the cardiac cycle and contractile state of the myocardium at the time of impact.

The degenerative changes observed in our study in cardiac muscle of baboons subjected to high-g. forces consist of random areas in which there is disruption of the myofibres by transverse separation and apparent rupture of the sarcolemma permitting separation of the fibrils. Nuclear changes are marked, some nuclei are swollen and ballooned, some are ghostly and indistinct, and some are shrunken, irregular in shape with condensed chromatin and surrounded by a clear zone, while others are frankly pyknotic. Lysis of nuclei appears to have occurred in the more severely affected areas. Vacuoles are present in many fibres and nuclei are eccentric in position. The theory that these are artifacts caused by a dull microtome knife is unconvincing because random areas of fragmentation usually adjoin relatively normal ones. The overall impression is that the changes described are the result of the tissues being subjected to extreme stress. A final interpretation will require further study.

FIGURE 8. Pericapsular hemorrhage of kidney occurring in single diagonal belt tests.

C. *3-Point System (Diagonal and Lap Belt Combination).* Since the 3-point restraint (American) configuration (Fig. 1–C) has not yet been used extensively in the United States, accident experience is still limited and injuries attributed to this system have been infrequently reported to date. A rupture of the spleen with fracture of five ribs, a fractured sternum,[24] and a hyper-flexion/hyper-extension cervical injury[20] have been reported as attributed to the American 3-point system. (In the American 3-point system, *both*[5] ends of the diagonal and lap belt are attached independently, while in the European 3-point system, there are only three points, one end of the lap belt continuing upward to form the continuous diagonal attachment.) Swedish studies have reported few injuries due to this system[4,7,8] and similar results have been reported from England[45] and Australia.[6,51] In a Dutch study, "three times as many chest and leg injuries" were found for diagonal and 3-point users as for lap belt users.[5] The major advantage of the 3-point system over either the single diagonal or the lap belt is that it offers additional protection by preventing flexion of the upper torso. Disadvantages appear to be that it must fit the occupant correctly to be effective, and that in side impact, the occupant on the side opposite the impact may slip out of the harness, while the occupant on the near side might receive cervical injury from neck impingement on the belt. Nevertheless, a properly worn 3-point restraint system is clearly an improvement over the lap belt.[57,58]

Table III provides data for three forward-facing, one 50° side-facing, and two 90° side-facing tests of the American 3-point system. In two forward-facing impacts at 20g. and 22g., no injury was found in one case and slight injury (pancreatic petechial hemorrhage, adrenal pericapsular hemorrhage, uterus broad ligament hematoma) in the other. A third test at 30g. (20° seat pitch, 74.2 ft./sec. velocity, 3,000 g./sec. onset rate for 0.095 sec. duration) also resulted in minor trauma (belt contusions—(Fig. 11)—dural congestion). The diagonal and lap belt combination appears to provide much better injury protection at this level of impact than the

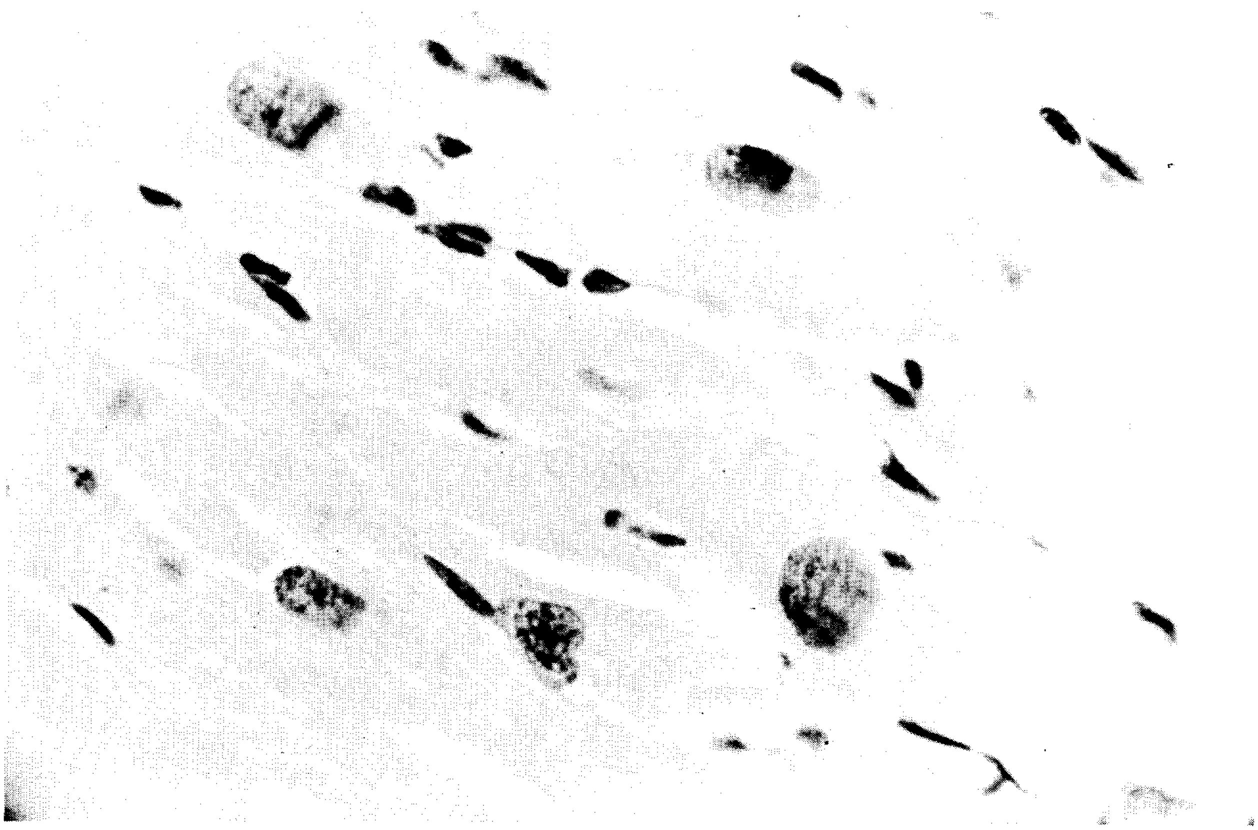

FIGURE 9. Giant nuclei in the muscle fibers.

lap belt only which appears to offer marginal survivability at 30g.

Two rearward-facing tests were run in this configuration. At 20g. no injury was found. At 40g., injury was not severe (subdural hemorrhage, subcapsular kidney hemorrhage, and petechial hemorrhages), and only the kidney and rib petechial hemorrhages are attributable to the belt (in rebound).

After one 50° left side impact at 22g., moderate intra-dural hemorrhage was found upon gross examination, and myofibrillar degeneration upon microscopic histological study.

Two 90° sideward-facing impacts (Table III–D) at 22g. and 30g. were run. At the lower level, severe dural and urinary bladder hemorrhage occurred, in marked contrast to the 22g. forward run where no trauma was found. At 30g. trauma was instantly fatal, due primarily to dislocation of the atlanto-occipital joint as the neck impinged upon the diagonal belt.

D. *Full-Torso Restraint.* The full-torso restraint (Fig. 1–D) consisting of lap belt and double shoulder harness has been long utilized in military training, and is required at flight deck crew stations of airline transport aircraft. Such systems have been extensively tested and have been demonstrated to be extremely effective.[23,65,82] Numerous versions (5-point, etc.) have evolved from this basic configuration. Because of the previously proven protective value of the full-torso restraint, only one animal was run in this series, and at 20g. neither gross nor microscopic trauma was found (Table IV).

E. *Inverted-Y Yoke Double-Shoulder Harness.* An experimental system, called the inverted-Y yoke double-shoulder harness, with inertia reel, (Fig. 1–E) was also tested in a series of three forward- and one 90° side-facing impacts (Table V).[60] This system offers the advantages of full-torso support while allowing free and complete movement of the occupant to reach controls and change position. It is comfortable, easy to slip into without mussing clothes, and fits women comfortably. Activation of most aircraft reels occurs at 2g., but in automobiles,

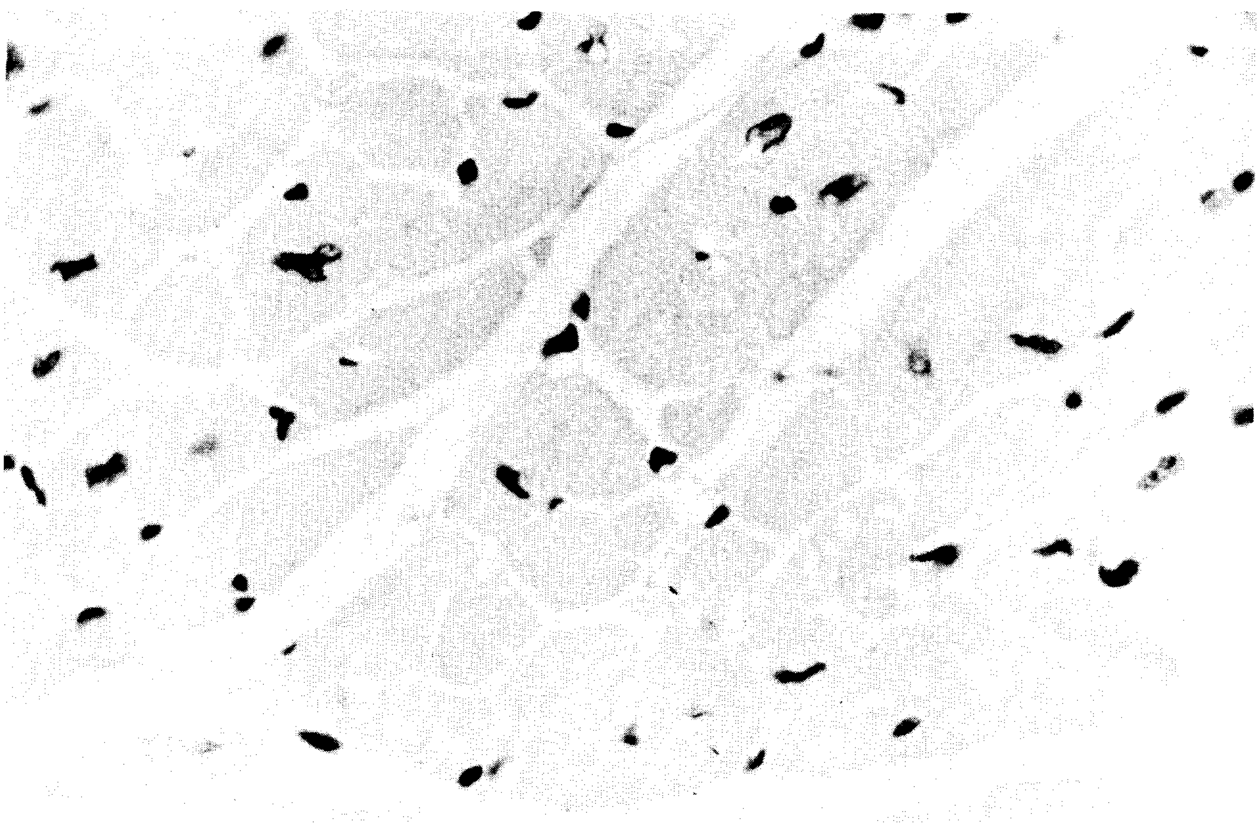

FIGURE 10. Interfibrillar edema and vacuoles in the myofibers are indicated by the lightly stained areas in longitudinally sectioned fibers.

0.3 to 0.5g. activation is necessary because of "panic braking" decelerations, not occurring in aircraft.

Tests were started initially at 30g., due to the estimated restraint capability of this system. At this level, in forward impact, trauma was minor, consisting of dural and lung congestion and cardiac micro-hemorrhage. At 43g. trauma was similar, except that a scapular fracture occurred as a result of belt impingement over the shoulder. Belt contusions were also observable. At 49 peak sled g., trauma was severe and probably fatal. Bilateral avulsion of the pectoralis muscles with severe contusions due to belt pressure was marked, and a partial dislocation of the humerus occurred. Dural congestion and pericardial, adrenal, uterine, and abdominal wall hemorrhages were found. Again, myocardial fragmentation was observed.

One left sideward-facing impact was run at 32g., a severe side impact. An artifact occurred when the subject's head struck the side panel upon rebound, resulting in fatal cranial fracture and cerebral hemorrhage. Other trauma was not significant and further tests should be conducted.

F. *Air-Bag Restraint Tests.* Nine tests with seven subjects were run in the forward-facing orientation (seat pitch 13°) with an experimental air-bag restraint system (Fig. 1–F) developed by Eaton, Yale & Towne, Inc.[60] Entrance velocities ranged from 71 to 94.1 ft./sec. with onset rates of 3,300 to 6,000 g./sec., and with durations from 0.040 to 0.060 second. Peak g. forces varied from 33 to 57g. (Table VI). Tests were started at 33g., due to the anticipated capability of this system. This system consisted of a lap belt restraint and an air bag, which was folded into a panel 10″ in front of the subject (Fig. 12). Upon impact, the bag inflated before the subject began moving forward (Fig. 13). As impact occurred, the gas was vented through two side holes, forming a dynamic system, and gradually decelerating the subject while distributing the load over his body. These were, to our knowledge, the first experimental tests of a dynamic air-bag system under controlled simulated crash conditions with living subjects.

FIGURE 11. Contusion resulting from impingement of 3-point restraint in 20g. impact at 60 ft./sec. velocity.

The patterns were as close to aircraft or automobile crash decelerations as the Daisy Decelerator could be programmed. Paired tests were run, with one animal at each level allowed to survive to permit study of post-impact chronic effects. One animal was run twice at 46 peak g. with no observable trauma and then was run a third time at 50g., after which autopsy revealed a ruptured bladder and dural congestion.

At 33g., the animal terminated and autopsied immediately post-impact revealed only slight dural congestion. A second animal, impacted at 36g. and allowed to survive for 90 days, was found to have no trauma.

At 47g., injuries to the terminated animal were dural congestion and lung, adrenal, and pancreatic hemorrhage. The paired animal, also run at 47g., but allowed to survive 30 days, showed

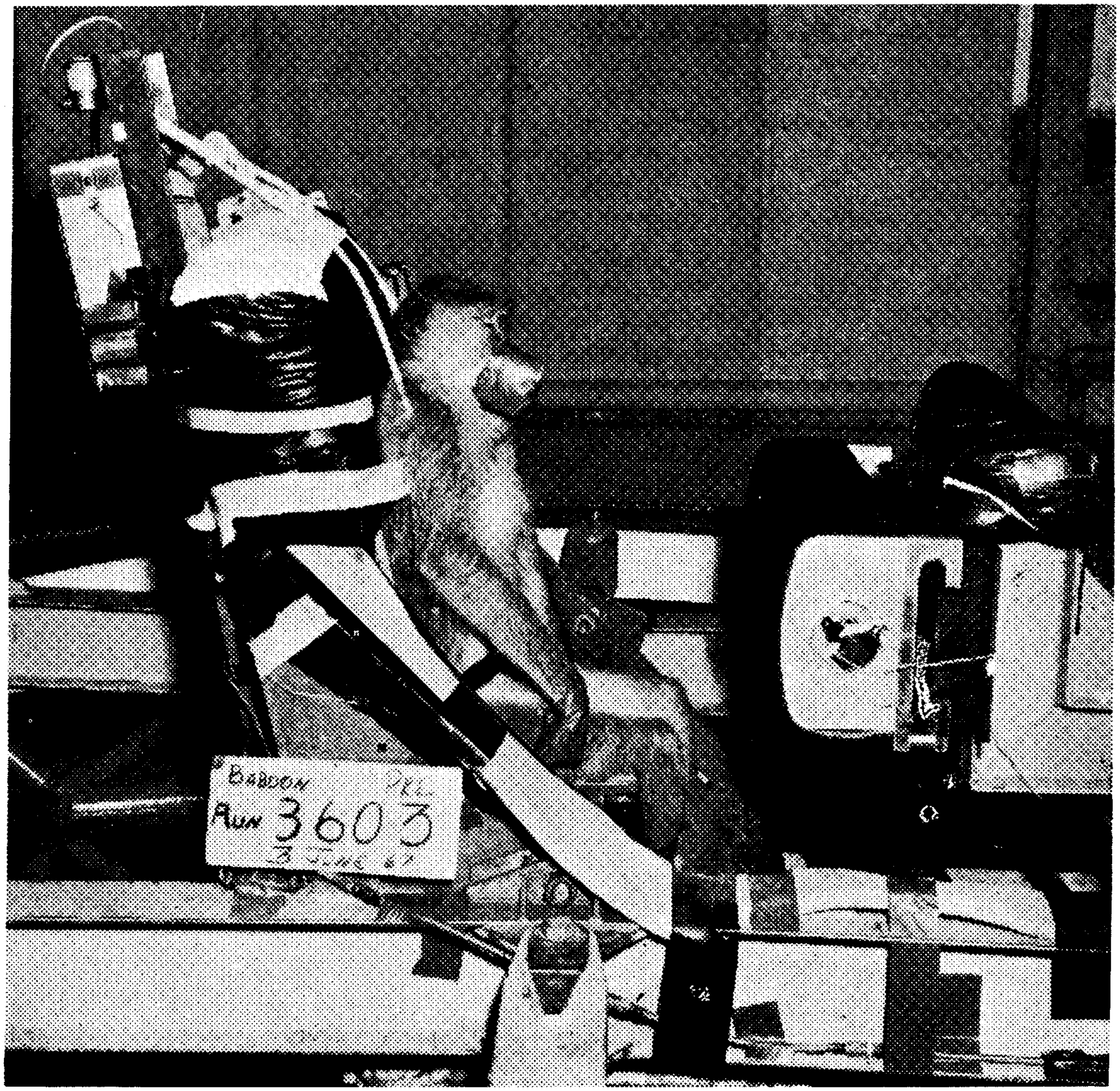

FIGURE 12. Baboon prior to impact run utilizing Air Bag Restraint System. Air bag is stored in panel 10 inches forward of animal and will be inflated at impact. The restraint holding arms will be released 0.6 sec. prior to impact.

no gross trauma, and slight emphysema upon microscopic examination.

The final series at 55g., resulted in dural congestion, uterine broad ligament hemorrhage, and lung and liver congestion in the terminal animal, all considered minimal. The paired animal run at 57g. and allowed to survive 30 days prior to autopsy, was found to have no gross trauma. Microscopic trauma involved pulmonary edema, vesicular emphysema, and periadrenal hemorrhage. Blood biochemistry studies pre-impact, post-impact, and at 7-day intervals for 1 month on the surviving control animals did not indicate stress changes which can be meaningfully interpreted at this time. It is interesting to note that dural congestion, evident in each animal sacrificed immediately post-impact, was not found in the 30-day or 90-day post-impact controls. This may indicate that such injuries are transient in nature. There seems little doubt, on a relative and comparative basis, that the air-bag restraint system is reaching a stage in development where it may have practical application.

The baboon's impact tolerance limits with this system appear to be much greater than the 57g. tested.

IV. Conclusions

The tests reported in this study demonstrate that while restraint systems may protect the occupant from the very serious trauma that may be caused by ejection or "secondary collision," they may in themselves act as sources of generally less lethal but yet significant injury. Such findings indicate that still a third-order of collision phenomena ("tertiary collision") should be the

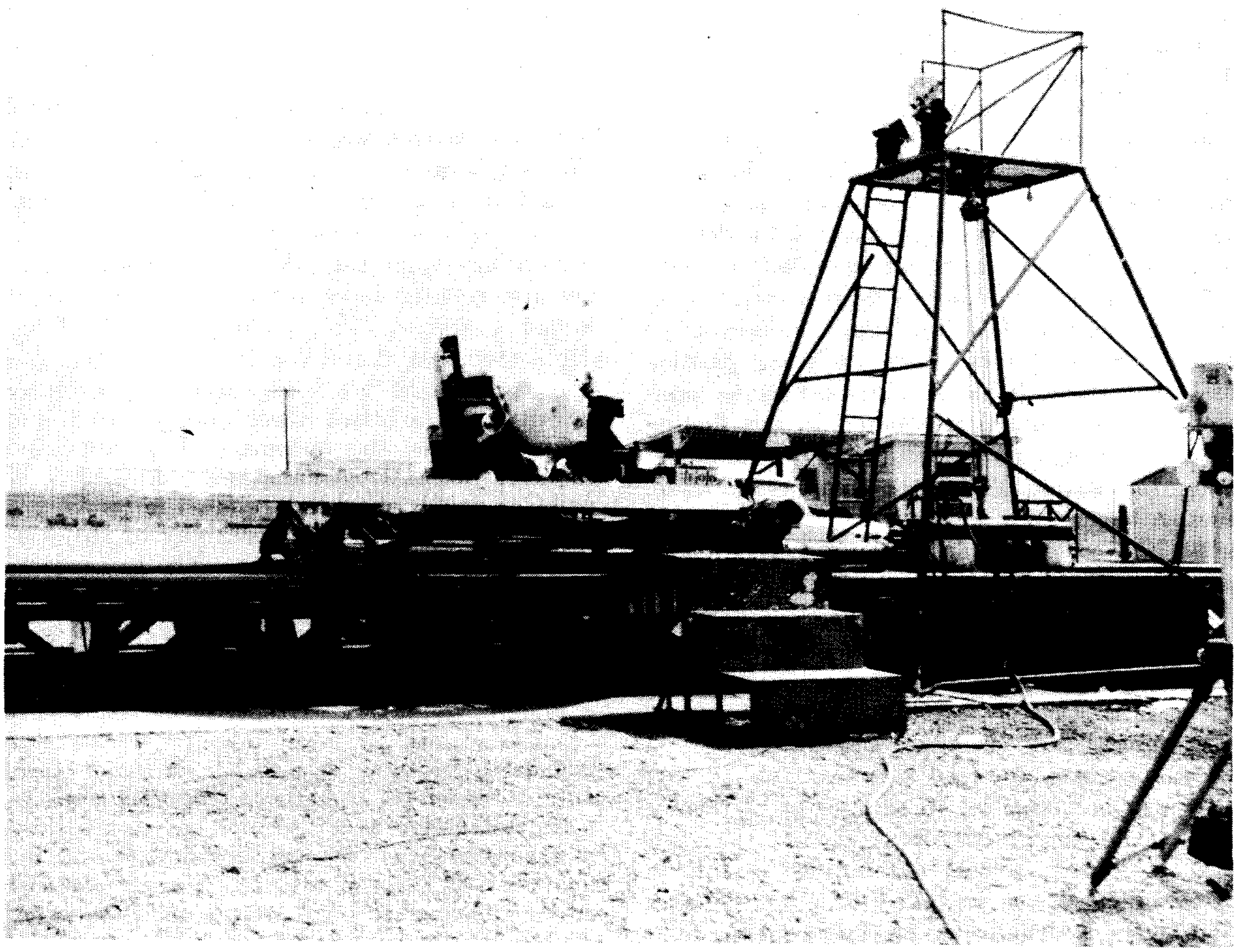

FIGURE 13. Inflation of the Air-Bag Restraint at moment of impact.

subject of intensive research. "Tertiary collision injury" may be defined as the trauma resulting from the interaction of the occupant and his restraint system. That such phenomena occur must not, however, serve as argument against the utilization of restraint systems, since these latter give significant needed protection from extreme impact. Rather, these phenomena must be viewed as analogous to the untoward side effects of an otherwise life-saving drug—effects which may be eliminated through further research.

These experiments also provide cogent and quantifiable argument for considering the effects of variation in occupant position in determining the lethality of a given "dose" of deceleration. In general, it may be stated that for the baboon restrained by lap belt alone, rearward-facing impacts are in terms of sustained g.-forces, about three times as tolerable (40–45g. survivable) as side-facing impacts (15–20g. survivable). Forward-facing impact orientations result in injuries intermediate in degree (25–35g. survivable). While the quantitative extrapolation of these findings into deceleration parameters (peak, onset rate, and duration of g.-forces) for the human situation may not be simple, the structural homologies of the baboon and human provide much conviction that there is a distinct correlation between them for the effects of position at impact. In other words, in humans, as in baboons, a given "dose" of impact appears to be most tolerable in the rearward-facing position and least tolerable in the sideward-facing position. From a practical standpoint, this finding would argue against the utilization of side-facing seats for airline stewardess jump seats where incapacitation of a stewardess may disastrously affect the controlled and orderly evacuation of an entire plane load of passengers.

These tests demonstrate that abrupt deceleration may have potentially grave effects that may not necessarily be correlated with the degree of tissue disruption or with the magnitude of impact forces. For example, fetal death occurred in all pregnant animals impacted although (a) irreversible anatomical trauma to the mother or fetus could not be demonstrated, and (b) position at impact, a very significant variable in determining the survivability of adult animals, had no apparent influence on results for the fetus since rearward- as well as forward-facing impacts resulted in fetal demise. A second example demonstrating the lack of correlation between overt trauma and injury potential is the effect of impact on the pancreas. In this organ, although the actual degree of tissue disruption was slight, its consequences (acute sterile pancreatitis) would have been extremely serious.[2]

Another finding is the occurrence of myofibrillar degeneration. This finding, described by others[49,50] as an agonal change of the myocardium associated with sudden death, has been dismissed as artifactual by some pathologists. Others have, while cautious, allowed that it might represent a subtle but genuine histopathological change of obscure mechanism. If the latter interpretation is correct, the changes observed definitely represent pin-point areas of perhaps irreversible myocardial degeneration, and it would be interesting to know what effects such lesions may have on myocardial function months or even years after impact. Similarly, in the kidney the minute areas of interstitial hemorrhage, while not lethal, might ultimately profoundly affect the function of that organ.[57]

In these tests, the trauma potential of several restraint systems was examined and composed. The single diagonal chest restraint resulted in immediate fatal injuries at the g.-levels tested. Simple lap-belt restraints were more effective in preventing injury than the single diagonal belt, but also resulted in serious and fatal injuries at higher g.-forces. The small sample precludes dogmatism, but the available evidence indicates that "loose-high" lap belts contribute to injury severity greater than those snugly fitted and worn low over the abdomen. Lap belts and shoulder harness combinations (American 3-point or double shoulder) resulted in less injury in this series of tests than did any of the commonly used restraint systems. The two experimental devices, Y-yoke with inertia reel and, especially, the air-bag restraint system, gave maximum protection to the occupant against tertiary collision injury.

Finally, tests such as these demonstrate that adequate evaluation of any restraint system must include experiments with living animals. Tests on anthropomorphic dummies, cadavers, and human volunteers can all contribute significantly to the development of restraint devices, but the final test of their effectiveness lies in, and can only be determined by, the response of the living system to an impact profile with parameters simulating as closely as possible those of actual accident environments.

APPENDIX A

TABLE I
LAP BELT TESTS

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY: GROSS	PATHOLOGY: MICROSCOPIC	PHYSICAL DATA SUMMARY – SLED: Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration (secs): Plateau	Time Duration (secs): Total	Peak Belt Force (lbs) Lap: Right	Peak Belt Force (lbs) Lap: Left
A. FORWARD FACING BODY ORIENTATION ($-G_x$)												
1	3636	27.5	Hemorrhagic Meninges	Endometrium Hemorrhage Slight Leptomeninges Hemorrhage	16.5	20^o	38.2	1500	0.056	0.094	330	350
2	3586(1)	30	Moderate Intradural Congestion Interlobular Hemorrhages Lungs, Subserosal Congestion	Adrenal Congestion	17	13^o	54.8	1400	0.080	.121	780	780
3	3362(1)	—			20	45^o	60.3	2000	0.080	—	—	—
4	2882(2)	—			20	45^o	63.1	1500	0.080	—	—	—
5	2888(1)	—			20	45^o	60.3	2000	0.080	—	465	540
6	2885(2)	—			20	45^o	63.3	2000	0.080	—		
7	3313(1)	—	Linear Abdominal Contusion (belt) with Subcutaneous Hemorrhage	Moderate Dural Congestion	22	20^o	61.0	2000	0.075	.103		
8	3582(1)	33	Moderate Congestion, Spleen Moderate Dural Congestion		22	13^o	63.9				870	900
9	3635(1)	25	Hemorrhage, Apex of Heart Meninges, Hemorrhage	Dural Hemorrhage Leptomeninges Congested	22	20^o	51.0	2050	0.053	0.089	450	450
10	3311		Pancreatic Petechial Hemorrhages Uterine Broad Ligament Hemorrhage		22	20^o	61.3	3350	0.075	.110		
11	3633	2	Contusion Lower Abdomen (belt) Subperitoneal Hemorrhage Meningeal Hemorrhage	Pancreatic Hemorrhage Adrenal Medulla Hemorrhage Endometrium Hemorrhage Dural Hemorrhage	26	20^o	60.5	1550	0.050	0.094	550	520
12	3634	21	Intercostal Subpleural Hemorrhage Moderate Linear Bruising, Abdomen (belt) Rectal Subserosal Hemorrhage Subserosal Uterine Hemorrhage Epidural Hemorrhages Petechial Hemorrhages, white matter	Meningeal Engorgement	28	20^o	72.9	2700	0.057	0.093	720	640
13	3372(3)	—	Laceration Left Flank Contusion, Lower Abdomen (belt) with Subcutaneous Hemorrhage Hemorrhages, Thymus Hemorrhage, Kidney Pelvis Dural Congestion	Hemorrhage, Lungs Hemorrhagic Thymus	30	20^o	74.2	3000	0.055	0.094	—	—
14	3126	—	Contusion, Lower Abdomen (belt) Pancreatic Subcapsular Hemorrhage Rupture, Quadriceps m. Insertion Moderate Intradural Hemorrhage	Cardiac Interstitial Hemorrhages Meningeal Hemorrhages Slight Dural Hemorrhage	31	20^o	74.2	3050	0.056	0.091	780	720
15	3125	—	Dural Interstitial Hemorrhage Moderate Dural Congestion	Lung, Alveolar Hemorrhage Pancreatic Interlobular Hemorrhage Urinary Bladder Hemorrhage	31	20^o	74.4	3100	0.056	0.091	720	630
16	3317(4)	—			33	20^o	74.3	5500	0.057	0.085	—	—
17	3315(3)	—			34	20^o	77.7	6800	0.055	0.078	—	—
18	2880(2)	—			40	45^o	87.0	4000	0.080	—	—	—

(1) Pregnant
(2) Implanted Artificial Uterus
(3) Loose-high belt
(4) Instrumented Pregnant Cadaver

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LAP BELT TESTS

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY: GROSS	PATHOLOGY: MICROSCOPIC	PHYSICAL DATA SUMMARY: SLED: Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration (secs): Plateau	Time Duration (secs): Total	Peak Belt Force (lbs) Lap: Right	Peak Belt Force (lbs) Lap: Left
B. 90° SIDEWARD FACING BODY ORIENTATION ($-G_y$)												
19	3027	24	Meningeal Congestion	Lung Edema Pericapsular Adrenal Hemorrhages	15	20°	36.4	1200	0.055	0.098	390	240
20	3028	25 1/4	Meningeal Hemorrhages	Lung Edema	16.5	20°	38.3	1350	0.050	0.091	395	205
21	3015	27 3/4	Linear Transverse Contusion Abdomen (belt) Subcutaneous Hemorrhage Severe Contusion, psoas m. Interstitial Hemorrhage Slight Hemorrhage, Uterine Myometrium and Endometrium Epidural and Subdural Hemorrhage of Spinal Cord, Level Coccyx to T-10 Petechial Hemorrhage, Pancreas	Pancreatic Hemorrhages Subperitoneal Uterine Hemorrhage Psoas m., slight interstitial Hemorrhage Slight Subarachnoid and sub-ependymal Hemorrhage	20	20°	57.3	2100	0.067	0.095	520	370
22	3018	27 3/4	Linear Transverse Contusion Abdomen (belt) Massive Pancreatic Hemorrhage Slight Hemorrhage of Meninges	Pericapsular Hemorrhage, both Adrenals Slight Hemorrhage Ependyma of Lateral Ventricle and Leptomeninges in Sulci	20	20°	58.4	2300	0.068	0.083	540	350
23	3025	24 1/4	Contusion, Lower Abdomen (belt) Fracture, Left Radius & Ulna Ecchymotic Hemorrhage, Right Auricle Pancreatic Mesentery Interstitial Hemorrhage Subepithelial Uterine Hemorrhage Meningeal Hemorrhage	Edema, Lungs	23	20°	50.7	2400	0.054	0.091	630	410
24	3130	—	—	—	23	20°	60.4	2550	0.063	.100	570	360
25	3128	—	Contusion, Lower Abdomen (belt) Ruptured Urinary Bladder at Neck Subperitoneal Hemorrhage Left Flank Extensive Sub-dural Hemorrhage Rupture, Basilar Blood Vessels	Rupture of Circle of Willis, Rt. Branch Hemorrhage, Aqueduct of Sylvius Hemorrhage, 4th Ventricle	26.5	20°	60.9		0.045	.100	555	360
26	3030	28	Ecchymotic Hemorrhage, Pericardium Rupture of Urinary Bladder Subperitoneal Hemorrhage, Uterus Parietal Subperiosteal Hemorrhage Slight Epidural Hemorrhage Meningeal Hemorrhage	Adrenal Medulla Hemorrhage Urinary Bladder Hemorrhage	27.5	20°	62.1	2100	0.048	0.091	780	480
27	3031	24	Contusion, Lower Abdomen (belt) Contusion, Rt. Posterior Leg Subperitoneal Hemorrhage, Abdomen Rupture, Urinary bladder Subperitoneal Hemorrhage, Uterus Meningeal Hemorrhage	Moderate Edema, Lungs Interlobular Hemorrhage, Pancreas Adrenal Medulla Hemorrhage Endometrium Hemorrhage, Uterus	28	20°	62.	2150	0.060	0.094	800	330
28	3123	—	Extensive Hemorrhage, Anterior Mediastinum Parapancreatic Hemorrhage Intracapsular Kidney Hemorrhage Ruptured Urinary Bladder Severed Uterus Above Cervical Canal Retroperitoneal Hemorrhage Complete dislocation, Occipital-Atlantoid joint Extensive m. avulsion each flank Subserosal Hemorrhage Moderate Hemorrhages, Lateral Ventricle Cerebellar Hemorrhage	Cardiac Hemorrhages Interlobular Pancreatic Hemorrhage Intermuscular Hemorrhage Urinary Bladder Leptomeningeal Hemorrhage Hemorrhage of Cerebral and Cerebrum Vessels Hemorrhage, Lateral Ventricles, 4th Ventricle and Cerebellum	30	20°	74.8	2600	0.058	0.096	540	490

TABLE I
LAP BELT TESTS

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY		PHYSICAL DATA SUMMARY							
					SLED						Peak Belt Force (lbs) Lap	
									Time Duration (secs)			
			GROSS	MICROSCOPIC	Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Plateau	Total	Right	Left
29	3023	22 1/2	Transverse Abdominal Contusion (belt) with Subcutaneous Hemorrhage Mediastinal Hemorrhage Dislocation of Occipitus and Atlas Pancreatic Interstitial Hemorrhage Ascending Colon Mesentery Interstitial Hemorrhage Retroperitoneal Hemorrhage, Pelvic Cavity Contusion, Uterus Meningeal Hemorrhage Severe Subdural Hemorrhage Subarachnoid Hemorrhage Spinal Cord Severed, Occipital-Atlantoid Junction	Lung Edema Liver, Hemorrhage Leptomeningeal Hemorrhage of Cerebrum Submeningeal Hemorrhage of Spinal Cord	30	20^{o}	75	3000	0.056	0.096	840	520
30	3022	26	Fracture, Left Ulna and Radius Transverse Abdominal Contusion (belt) Abdominal Hemorrhage Hemorrhage, Left Ventricle Meningeal Congestion	Lung Edema	30.5	20^{o}	73.6	3050	0.055	0.094	830	570
31	3122	—	Fracture, Left Ulna and Radius Extensive Hemorrhage at Sternum Bilateral Hemothorax Pancreatic Hemorrhage Retroperitoneal Hemorrhage, Left Adrenal Retroperitoneal Hemorrhage, and Intracapsular Hemorrhage, Kidneys Subserosal Hemorrhage, Bladder Avulsion, Head of Quadriceps m. Bilateral Rupture, Diaphragm	Myocardial Micro-Hemorrhage Interlobular Hemorrhage Pancreas Dural Congestion	31	20^{o}	74.6	3100	0.053	0.097	780	480
32	3369	26	Subcutaneous Hemorrhage, Right Axilla; above Pubis Ruptured Uterus; Laceration, Bladder Subserosal Tears, Uterus; Rectal Peritoneal Tear	—	31	20^{o}	74.8	3100	0.055	0.093	600	—

C. REARWARD FACING BODY ORIENTATION ($+G_x$)

Test	Daisy Test No.	Wgt. (lbs.)	GROSS	MICROSCOPIC	Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Plateau	Total	Right	Left
33	3131	—	Pancreatic Interlobular Hemorrhage Marked Subdural Hemorrhage	Sub-ependymal Hemorrhage Lateral Ventricle	22	20^{o}	59.9	2950	0.065	.100	35	30
34	3132	—	Bruise, right Buttock Dural Congestion	Hemorrhage into Alveolar Spaces Patchy Edema, Lungs	23	20^{o}	59.0	2300	0.051	0.088	30	30
35	3133	—	Subserosal Hemorrhage, Uterus Intradural Hemorrhage Moderate Epidural Hemorrhage	Meningeal Congestion	31.5	20^{o}	74.1	2650	0.054	0.095	30	65
36	3134	—	Extensive Abdominal Bruising Numerous Hemorrhages, Left Ventricle Subserosal Hemorrhage, Urinary Bladder Moderate Sub-dural Hemmorhage	Lung Edema	44	20^{o}	88.0	5850	0.047	0.076	75	120

TABLE II
DIAGONAL BELT TESTS

Test	Daisy Test No.	Wgt.	PATHOLOGY: GROSS	PATHOLOGY: MICROSCOPIC	PHYSICAL DATA SUMMARY: Peak G	Seat Pitch	SLED: Ent. Vel.	Onset Rate (g/sec)	Time Duration (secs): Plateau	Time Duration (secs): Total
A. FORWARD FACING BODY ORIENTATION ($-G_x$)										
38	3316	28.5	Diagonal Linear Contusion (belt) Sternal Subcutaneous Hemorrhage Marked Left Pleural Hemorrhage Intracapsular, Subcapsular Hemorrhage, Left Kidney Thoracic Subcutaneous and Intermuscular Hemorrhage Kidneys, Pericapsular Hemorrhage Spleen Ruptured Left 8, 9, 10 ribs fractured Liver Extensive Lacerations Subserosal Hemorrhage, Stomach Hemorrhages, Greater Omentum Sigmoid Colon, Ruptured Adrenal Pericapsular Hemorrhage Subperitoneal and Interlobular Hemorrhage, Pancreas Dural Congestion	NOT DONE	30	20^o	75.8	4000	0.085	.117
39	3371(1)	27	Myocardial myomalacia Intra-alveolar Lung Hemorrhage Subarachnoid Hemorrhage Diagonal Linear Contusion (belt)	Fractures of Sternum; L. 3rd Rib Dislocation Rt. Clavicle Amputation, Rt. Mammary Gland Nipple Broad Contusion Thorax (belt line) Extensive Rupture & Avulsion; Rt. Pectoral M., Deltoid m., Biceps m. Anterior Mediastinal Hemorrhage Hemorrhage Left Pectoral m. Hematoma, Right Auricle Subpleural Hemorrhage, Rt. Apical Lobe Hemorrhage Left Kidney Pelvis Dural Congestion	30	20^o	74.7	3000	0.054	0.093
B. 90^o SIDEWARD FACING BODY ORIENTATION ($-G_y$)										
40	3368	28.2	Myocardial Hemorrhage Subendocardial Scarring of Cordae Intra-Alveolar Hemorrhage, Lungs Moderate Dural Hemorrhage Diagonal Linear Contusion (belt)	Severe Contusions, Rt. Chest (belt) Massive Bilateral Subcutaneous Hemorrhage Avulsion, Rt. Pectoral m. Severe Intermuscular Hemorrhage L. Pectoral m. Rt. Ribs 2-6, Comminuted Massive Destruction Entire Rt. Chest Wall Extensive Hemorrhage, Thoracic Cavity Intercostal m. Hemorrhage, 1-3, Left Pericardial Ecchymotic Hemorrhage Marked Anterior Mediastinal Hemorrhage Laceration, Rt. Lung Hemorrhage, Lungs, Bilateral Hemorrhage, Hylus of Liver Pancreatic Hemorrhage Rt. Adrenal, Pericapsular Hemorrhage Dural Congestion	30	20^o	74.6	3000	0.055	0.091

(1) Right lower diagonal belt force 960 lbs.;
Left upper 1020 lbs.

TABLE III
3-POINT (DIAGONAL AND LAP BELT) TESTS

			PATHOLOGY		PHYSICAL DATA SUMMARY									
					SLED				Time Duration (secs)		PEAK BELT FORCE (LBS)			
											Lap		Diagonal	
Test	Daisy Test No.	Wgt. (lbs.)	GROSS	MICROSCOPIC	Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Plateau	Total	Right	Left	Top Right	Bottom Left
A.	FORWARD FACING BODY ORIENTATION ($-G_x$)													
41	3314(1)	27.2	None	None	22.2	20°	61.2	2000	0.072	0.098			490	160
42	3310	26.8	Petechial Hemorrhage, Head of Pancreas Broad Ligament Hematoma Subchorionic Hemorrhage Insertion of Cord	Adrenal Pericapsular Hemorrhage, slight	20.5	20°	60.4	2750	0.073	.115	450	450	750	750
43	3370	26.8	Transverse Contusion (lap belt) Dural Congestion, moderate, bilateral	Arachnoid Hemorrhage of Pons, Slight	30	20°	74.2	3000	0.057	0.095	545	310	720	490
B.	REARWARD FACING BODY ORIENTATION ($+G_x$)													
44	3365(2)		None	None	20.2	20°	60	2550	0.074	.108	0	0	15	15
45	3364(3)	25	Subpetechial Hemorrhages either side T-7 to T-12 Bilateral Subdural Hemorrhages Petechial Hemorrhage over Ribs, Extensive Subcapsular Hemorrhage Anterior Left Kidney	No Report	40.4	20°	84.4	5400	0.052	0.077	18	0	25	50
C.	50° SIDEWARD FACING BODY ORIENTATION ($-G_y$)													
46	3587	36	Uterine Subserosal Congestion Mod. Intradural Hemorrhage Intratentorial Hemorrhage	Myocardial Myomalacia	22	13°	59.1	2200	0.062	.102	480	270	430	720
D.	90° SIDEWARD FACING BODY ORIENTATION ($-G_y$)													
47	3586	34.5	Subpleural Hemorrhage, L. Lung Slight Intracapsular Hemorrhage L. Kidney Slight Intracapsular Petechial R. Kidney Retroperitoneal Hemorrhage, Severe Marked Hemorrhage Bladder ligaments (Fetus, Dural Hemorrhage)	Subpleural Hemorrhage Urinary Bladder Hemorrhage Severe Brain Hemorrhage	22.2	13°	59.8	2200	0.062	.102	480	—	—	900
48	3367	26.6	Total Dislocation, Occipital-Atlantoid Joint Mod. Bilateral Intradural Hemorrhage Contusion, left side Neck Transverse linear Contusion (lap belt) Subcutaneous Hemorrhage Right Mandible Subpleural Subpleural Ecchymotic Hemorrhages left, 3-6 ribs; Right 2-6 ribs Uterine Hemorrhage Sternocleidomastoid fascia Hemorrhage Extensive right intramuscular Hemorrhage (Right shoulder), Left Thoracic Wall 3-7 ribs; 11-13 ribs	Intra-alveolar Hemorrhage Leptomeningeal Hemorrhage Perivascular Hemorrhage Cerebral vessels Hemorrhage Ventricular Hemorrhage Subarachnoid Hemorrhage	30	20°	74.5	2950	0.054	0.093	750	270	990	940

(1) 153 days pregnant. Terminated post-impact. Fetal death 10 hr. post Caesarian Section
(2) 110 days pregnant. Fetus died 2-1/2 hrs. post-impact, placental separation.
(3) 145 days pregnant.

TABLE IV
FULL TORSO TEST

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY		PHYSICAL DATA SUMMARY					
					SLED					
			GROSS	MICROSCOPIC	Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration (secs)	
									Plateau	Total
A. FORWARD FACING ($-G_x$)										
49	2586	34	NONE	NONE	20	45°	63.6	2000	0.080	–

(1) Implanted, artificial uterus

TABLE V
YOKE RESTRAINT TESTS

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY: GROSS	PATHOLOGY: MICROSCOPIC	PHYSICAL DATA SUMMARY: SLED: Peak G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration (secs): Plateau	Time Duration (secs): Total	PEAK BELT FORCE (LBS.): Lap: Right	Lap: Left	Diagonal: Right	Diagonal: Left	Yoke
A. FORWARD FACING BODY ORIENTATION ($-G_x$)															
50	3601	33.5	Dural Congestion	Cardiac Hemorrhage Lung Congestion and Edema	30	13°	73.6	2700	0.054	0.094	440	440	420	360	—
51	3666	32	Dural Congestion Bilateral Contusions of Anterior Axillary Folds and Adjacent Deltoid Areas Abdominal Contusions Scapular Fracture	Lung Edema Cardiac Hemorrhages Uterine Congestion	43	13°	88.0	5400	0.049	0.063	—	—	—	—	—
52	3665	28	Dural Congestion Pericardial Hemorrhage Broad Ligament Hemorrhage Mesentery Hemorrhage Abdominal Wall Hemorrhage Bilateral Avulsion of the Pectoralis Major Muscles Incomplete Bilateral Avulsion of the Pectoralis Minor Muscles Bilateral Contusions of Shoulder-Neck Area Incomplete Displacement of Humerus	Adrenal Congestion and Hemorrhage Myocardial Fragmentation Pyknosis and Karyolysis of Nuclei of Myocardial Fibers	49	13°	94.4	6100	0.045	0.073	780	650	490	420	—
B. 90° SIDEWARD FACING BODY ORIENTATION ($-G_y$)															
53	3580	30	Cranial Fracture Dural Hemorrhage Abdominal Contusions	Cardiac Hemorrhage Cerebral Hemorrhage Lung Edema and Hemorrhage	32	13°	75.2	4300	0.060	0.093	960	360	450		960

TABLE VI
AIRBAG RESTRAINT TESTS

Test	Daisy Test No.	Wgt. (lbs.)	PATHOLOGY		PHYSICAL DATA SUMMARY								
					SLED							PEAK Lap Belt LOADS (LBS)	
			GROSS	MICROSCOPIC	Peak G	Ave G	Seat Pitch	Ent. Vel. (ft/sec)	Onset Rate (g/sec)	Time Duration (secs) Plateau	Time Duration (secs) Total	Right	Left
A. FORWARD FACING BODY ORIENTATION ($-G_x$)													
54	3595	32.5	Dural Congestion	NONE	33	30	13^o	71.0	3300	0.060	0.091	450	450
55	3597(1)	34.0	NONE	NONE	36	33	13^o	74.0	3700	0.056	0.086	410	360
56	3598(2)	15.5	Rerun No Autopsy		46	37	13^o	85.6	4900	0.047	0.076	410	375
57	3599(2)	15.5	Rerun No Autopsy		46	37	13^o	85.1	4600	0.052	0.081	300	240
58	3600(2)	15.5	Dural Congestion Bladder Rupture	Bladder Hemorrhage	50	39	13^o	86.0	5600	0.048	0.074	330	300
59	3601	20.5	Dural Congestion	Lung Hemorrhage and Edema Pancreatic Hemorrhage Adrenal Hemorrhage	47	37	13^o	85.4	5300	0.047	0.075	360	420
60	3602(3)	25.0	NONE	Atelectasis; Emphysema Pigment Macrophages	47	42	13^o	85.7	4900	0.046	0.075	600	600
61	3603	22.0	Dural Congestion Broad Ligament Hemorrhage	Lung Congestion Liver Congestion	55	50	13^o	94.0	6000	0.040	0.059	640	600
62	3604(3)	26.5	NONE	Pulmonary Edema Pigment Macrophages Vesicular Emphysema Periadrenal Hemorrhage	57	50	13^o	94.2	5900	0.061	0.079	540	510

(1) Allowed to survive 12 weeks post-impact
(2) Same animal
(3) Allowed to survive 4 weeks post-impact

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