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Experimental Comparison of Trauma in Lateral $(+G_y)$, Rearward Facing $(+G_x)$, and Forward Facing $(-G_x)$ Body Orientations When Restrained by Lap Belt Only

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In this study, 24 anesthetized Savannah Baboons (*Papio cynocephalus*) restrained with a lap belt were subjected to a controlled series of lateral impacts at entrance velocities ranging from 36.4 ft/sec (15G) to 88.2 ft/sec (44G), 1200 g/sec to 5900 g/sec rate of onset, for total durations of 0.076 to .100 seconds. Sixteen lateral ($+G_y$) tests were run with four forward-facing ($-G_x$) and four rearward-facing ($+G_x$) controls.

Gross and microscopic autopsies were performed. Pathology was found to be significantly higher in lateral impact. Ruptured bladders and uteri, adrenal hemorrhage, and subdural and epidural hemorrhage occurred frequently. A major finding, with unexplained etiology, was marked pancreatic hemorrhage most typical of the lateral impact. Under these test conditions, both survival and injury tolerance levels were found to be lower in the lateral ($+G_y$) body orientation, indicating lap belt restraint alone does not provide adequate body protection.

CONSIDERATION OF RESTRAINT protection of occupants in aircraft or other vehicles has emphasized the forward or rearward facing positions, which are most commonly utilized. However, in many instances individuals are normally transported laterally to the direction of flight, as occurs in commercial aircraft, either involving aircrew positions occupied by the flight engineer or stewardesses, or by passengers in lounge seating. Many military aircraft and especially troop helicopters still utilize sideward-facing passenger and crew positions. On the ground, people travel "sideward" in busses, on trains, and subways, as well as in other specialized vehicles. In addition, lateral loadings in the $\pm$ Gy body axis commonly may occur to individuals in automotive collisions during side impacts, may occur with capsular ejection systems in landings, and may be experienced both in spacecraft and aircraft lateral oscillations and turbulence. The crash landing of most commercial aircraft and many general aviation types in the light-twin category will expose some occupants to lateral forces, and in addition any aircraft may skid sideways, thereby changing the main direction of force to a lateral one.

The question of the safety of crewmembers and passengers occupying sideward-facing seats in commercial aircraft has never been adequately investigated and, recently, serious concern has been expressed by representatives of the Steward and Stewardess Division of the Air Line Pilots Association, the Society of Automotive Engineers S-9 Cabin Safety Provisions Committee, and others. This study was initiated because of the lack of realistic data concerning the tolerance of the body to lateral impacts and knowledge of specific injury hazards not common to forward or aft-facing impact orientations. It was believed that insight into the particular problems or mechanisms of injuries would considerably aid in design of protective devices as well as assist in evaluation of present sideward-facing environments.

Previous evidence suggested that the body is less able to tolerate lateral impact[19] and that sideward-facing seat tie-downs and restraint may not provide adequate protection in crashes.[16] Injuries to passengers and at least one fatality to a crewmember have been documented. While the Air Force specifies 16G passenger seat strength requirements to face rearward,[9] the Federal Aviation Regulations (FAR 25.561) specifies design values for forward facing seats of 2.0g upward, 9.0g forward, 1.5g sideward, and 4.5g downward, while

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TSO C-250 (NAS 806 spec. 4.3.1.1) states "when a seat or berth is to be installed or adjusts to face in other than the forward direction, sufficient tests shall be made to substantiate the seat strength for all intended positions."[17] The interpretation of this ruling by Flight Standards Division, FAA, is that it is the manufacturer's responsibility to perform the necessary tests to insure that such seats meet these specifications. A seat designed for 1.5g sideward loading will not necessarily support 9.0g when turned 90°, so that the sideward load becomes the forward component. Upon inquiry, one manufacturer stated that they had run static tests to insure that that particular seat met specifications. Yet Haley, in a 1962 engineering evaluation of military personnel restraint, systems concluded "only dynamic tests can reveal the weak points of a restraint system . . . two seats, designed to equal *static* loads, will not behave the same when subjected to dynamic (crash) loads."[8] Turnbow et al. have reported that existing side-facing seats in U. S. Army aircraft were understrength and not designed to provide adequate restraint, recommending troop seats be designed for dynamic load factors of 26G for 0.20 seconds, and 45G for 0.10 seconds for lateral impact.[16]

However, research to support these requirements has mainly been theoretical calculations by engineers, based upon accident investigation. Earley,[5] in 1961, simulated the Electra lounge seat belt loadings in the sideward-facing position and found that, "belt tension loads in the side-facing seat may be 3 to 6 times greater than the belt load on a forward-facing seat under the same axial deceleration." The magnitude of the tension load in the belt may therefore be in the range of 3040 to 6020 pounds when the crash load is 9G $\times$170 lbs $\times$ 1.33 fitting factor. His calculations demonstrated that seat belt loads may be far above the normal expected in the forward seated position, so that this increased loading should be considered along with seat structure, tie-down, and body tolerances. In 1964, during FAA controlled crash tests of a Lockheed 1649 and Douglas DC-6B being conducted at Flight Safety Foundation (AV-SER) facilities, the sideward-facing seats collapsed, and no load recordings were obtained, although horizontal acceleration tracings from the aft floor of the Constellation (station 1175) appear not to have exceeded about 2G until 3.7 seconds, at which they reached 22G impact with a 20° upslope.

The lateral impact evaluations to date have revolved about the seat tie-down and restraint system and not the total environment, including consideration of human physiological tolerances. Our knowledge of human responses to lateral forces has been very restricted. Most previous studies, furthermore, have been conducted under conditions of maximum restraint, offering considerably greater protection to the body than does the lap belt only. Thus, early animal studies by Stapp, showing no injury in chimpanzees of 47G lateral accelerations (.140 seconds duration),[14] Robinson's exposures of rhesus monkeys to lateral impacts of 75G at up to 32 ft/sec velocities,[11] Clarke's successful lateral exposure of a bear to 47G (with rate of onset of 4180 g/sec) without injury,[4] and Lombard, et al.[10] exposure of guinea pigs to 240G for .033 seconds at 100,000 g/sec rate of onset in a fully contoured, rigid support restraint system, were conducted with the animals supported by maximum restraint systems. Initial design of the Apollo command module was restricted to a maximum acceleration of 10G with a rate of onset of not more than 250 g/sec, due to lack of definitive data on human tolerances to lateral forces.

A study by Clarke, Weis, Brinkley and Temple in 1963[4] on thirty-two human runs produced no adverse subjective responses to lateral impact up to 22G (maximum rate of onset of 1350 g/sec), and a subsequent study by Brown, Rothstein and Foster, in 1966[1,12] of 11 human tests, using a 3-inch lap belt, double shoulder harness, inverted "V" pelvic straps, and head restraint, found no injury from lateral impact at forces to 14G on the sled. A study by Zaborowski[18] on the Holloman "bopper" involved 87 tests on 52 male Air Force subjects at impacts up to 12G while restrained with both lap belt and shoulder harness and side restraint panel. Whitehouse[17] in 1966 reported 18 lateral (−Gy) impacts conducted on nine human subjects impacted at 15G, using head and torso restraint. Other tests in support of the B-58 capsule, Mercury, Gemini, Apollo, F-111 and other advanced experimental systems have also employed maximum restraint systems,[2] not comparable to that of minimal lap-belt-only restraint.

In contrast there apparently has been only one previously published study involving impact tolerance while restrained by lap belt only. Zaborowski, Rothstein, and Brown in 1965 published the first medical investigation on humans (restrained by lap belt only) in lateral impact and these had to be discontinued at 9G (with impact durations of 0.1 sec) due "to subject discomfort with prolonged stiffness and soreness in the neck musculatus."[17] Fish and Wright[7] have described injuries to four soldiers seated in center-facing seats of an Army Caribou troop transport. Further studies currently in progress by Sonntag[13] involve photometric analysis.

The objective of the series of tests reported here was to go beyond these subjective limits and attempt to established physical end-points of nonreversible trauma while restrained by lap belt only. The tests were intended to provide more valid data concerning, (1) what injuries are typical in a (± Gy) lateral impact, (2) where the initial injuries occur and at what force levels, (3) the mechanisms of these injuries, (4) the body kinematics in lateral impact, and (5) seat belt differential forces on left and right side during impact.

MATERIALS AND METHODS

Twenty-four deceleration tests were performed on twenty-four adult female Savannah baboons (*Papio cynocephalus*), ranging in body weight from 9.5 to 12.7 kg (21-28 lbs.) Age estimations based on dental examination ranged from 4½ to 12 years (CS). Animals were provided by CAMI through the breeding colony maintained for cardiovascular and stress research at the University of Oklahoma or from International Animal Imports, Detroit, and shipped by aircraft from one to

10 days prior to tests at Holloman AFB.

Tests were run between 23 May and 26 August 1966, utilizing the Daisy Decelerator of the 6571st Aeromedical Research Laboratory at Holloman AFB.[3] The seat was an F-111 test frame, modified for baboons, and mounted on the ARL Omni-Directional sled. The nylon lap belt of 4500-lb strength was replaced for each test and installed at a 55° angle to the seat pan. Prior to each run, static belt tension for each side was stabilized at 1.5 kg (3.3 lb) utilizing an Ohaus Cenco Model 5610 Scale. This provided the same degree of belt "tightness" for each subject.

Test conditions involved 0°-5°-0° seat orientation (seat sideward facing, 85° from horizontal) for all tests. Protocol was established for two runs at each level of impact at 15, 20, 25, 30, and 44G in the lateral position, and one run at each level from 15-30G in the forward-facing (−Gx) 180°-5°-0° and rearward-facing (+Gx) orientation. Time duration was to remain constant, but varied from 0.076-.100 seconds total duration, the longest time duration at 30G the Daisy track was capable of providing safely with this sled load. Entrance velocities varied from 36.4 ft/sec (15G) to 88.2 ft/sec (44G), and rate of onset from 1200 to 5900 g/sec.

Prior to each run the subject was anesthesized with 1 mg/kg body weight of Sernalyn.® She was then removed from the cage after the drug had taken effect and prepared for the test in an adjacent surgical room. Hands and feet were covered with tape to prevent the chance of injury to investigators and the animal was muzzled to prevent injury to the tongue during impact. Body measurements were taken with an anthropometer and sliding caliper. In some cases, previous longitudinal series of anthropometrics had been taken periodically on animals originating from the colony at the University of Oklahoma, and in these cases, only a few measurements were required. The animal was partially shaved down the chest, abdomen, and thigh, and tincture of Benzoin was smeared over the skin. Three-quarter-inch photometric "targets" were then placed in position on three-inch Dermicel surgical tape, which formed a contrasting background. Target locations for each animal were accurately measured. Five general locations included (1) head (30 mm posterior to glabella), (2) centered on the muzzle, (3) on the upper chest (40 mm inferior to suprasternale), (4) midchest (310 mm superior to symphysium), and (5) abdominal (150 mm superior to symphysium). The purpose of the "targets" was to provide information on body kinematics during impact through high-speed photometric camera coverage and computer analysis of acceleration, velocity and distance relationships with time. (Figure 1)

The animal was then taken to the track sled and the seat belt tension adjusted to 1.5 kg and positioned. Low strength masking tape was used to keep the legs and thorax in good position for the run; however, this tore upon impact and did not provide additional restraint protection. Muscle tonus was carefully monitored and all runs were made at the same clinical level.

The strain gages were fabricated for the 6571st Aeromedical Research Laboratory by Land-Air Division of Dynalectron at Holloman AFB. They were originally designed for a two-inch-wide belt but were modified to the one-inch webbing used in these tests. Gages were placed at each end of the belt, two for lap belts and the diagonal belt, and four were utilized for each 3-point harness. Each strain gage buckle was instrumented with four strain gages in order to measure the bending moment due to the force imposed on the belt. When the belt was stretched, the metal of the buckle was stressed and deflected. Although each buckle contained eight elements, it electrically appeared as a four active arm bridge. Resistance across the electrical elements changed as a result of changes of strain on the metal. Calibrations were done by placing a known force on the belt and measuring the electrical output of the bridge.

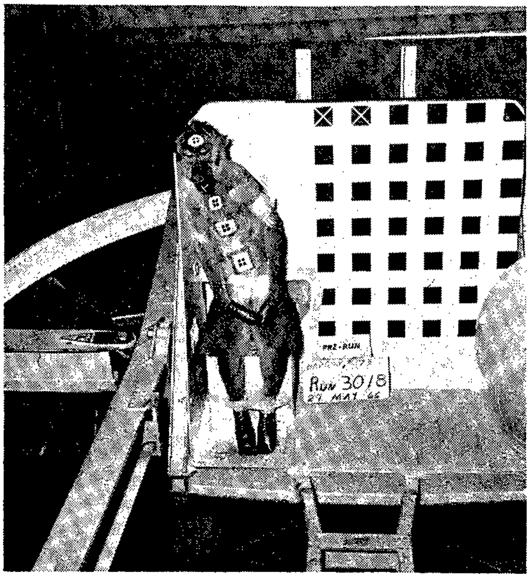

Fig. 1. Baboon positioned in seat on omnidirectional sled prior to impact run. Note photometric locators on animal and along left portion of seat back.

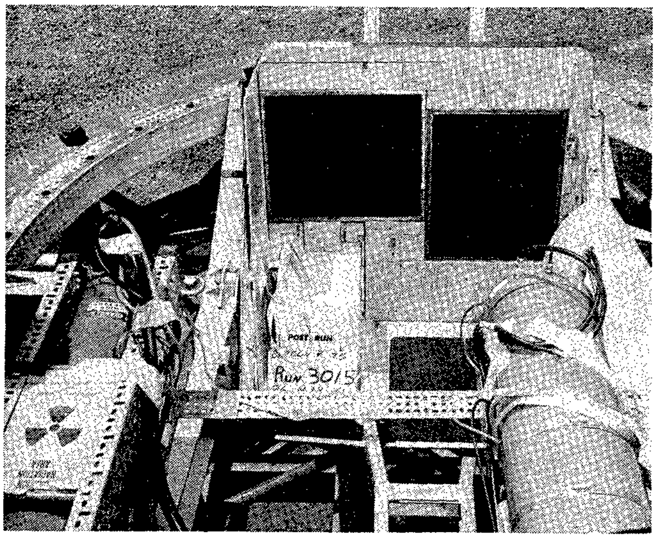

Fig. 2. Sled seat post-impact with photometric backing removed to show location of dual x-ray casettes mounting. One roentgenogram was obtained at impact and a second could be set for any time during the sequence of lateral movement.

Run coverage included use of Fastex 2000 fps cameras for frontal and side views, two Field Emission high-speed roentgenograms (Figure 2), (the first was triggered at impact and the second was triggered at about .65 seconds after initial sled entry into the brake), and a metric camera on the last 16 runs. In addition to 35 mm and 4.5 still photography, three polaroid photos were obtained during each run, pre-, during (Figure 3), and post-impact. These served as working references to note position and to cross-check details of notes. All animals were sacrificed post-run with 650 mg Nembutal® after post-run physical examination. They were then prepared for shipment in ice by air to CAMI for necropsy, which was generally accomplished within 24 hours.

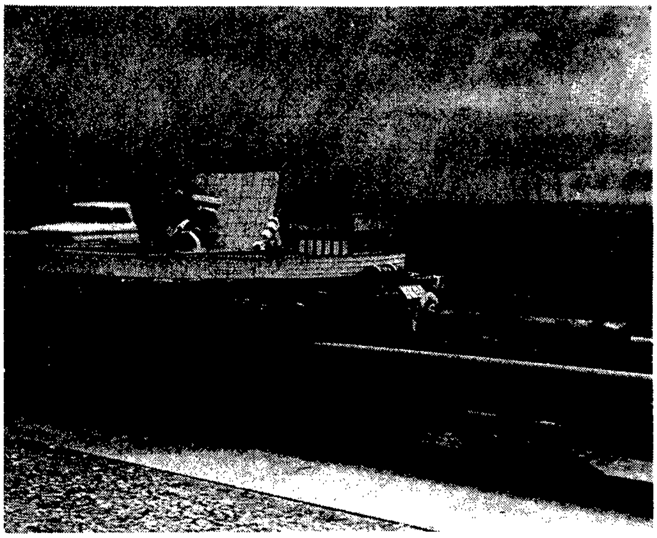

Fig. 3. Photo taken during one sideward-facing run on the Daisy Decelerator. Shoulder and leg tapes held animal in position only, shearing upon impact.

RESULTS AND DISCUSSION

Three series of impact tests were run to compare the effect of body orientation to force. Each of these tests is summarized in Table I. Peak G forces ranged from 15 to 44G in the lateral series, 16.5 to 31G in the forward facing series, and 22 to 44G in the rearward facing body orientation. Onset rates varied from about 1200 g/sec to about 5900 g/sec, and time durations (plateau) from 0.047 to 0.066 seconds, with total time durations ranging from 0.076 seconds to .100 seconds. Sled entrance velocities into the braking system ranged from 36.4 ft/sec (15G) to 88.2 ft/sec (44G).

In the lateral decelerations, impact was made in each case on the animal's left side, thus seat belt forces were greater on the right (or rear) belt. Since the majority of the baboon subjects weighed about 12 kg. (although one [test #3131] weighed 21 kg.), or 1/7 (to 1/3) that of an adult human male, the forces are proportionately lower. Forces on the right belt averaged 62 per cent higher than those on the left with a range from 38 to 94 per cent. In the four forward-facing runs, belt loads were, as expected, relatively close. Although lateral belt loads for the "rear" belt were higher at every G level than for the forward facing belt tensions, the relative differences were not found to be as great in this series

TABLE I. SUMMARY OF DECELERATION DATA

		Baboon				Sled				Seat Belt Tension (lbs)		
			Weight					Time Duration				Ratio %
Test No.*	Daisy Run	Age (Yrs.)	lbs.	Kg.	Peak G	Entrance Vel (ft/sec.)	Onset Rate (g/sec.)	Plateau	Total	Right	Left	L/R × 100
A. SIDEWARD-FACING SERIES (+Gy)												
1	3020	4½	26¼	11.9	44.0	87.1	4700	.044	.080	880	660	75
2	3122	7+	25½	11.5	31.0	74.6	3100	.053	.097	816	491	60
3	3123	7+	—	—	30.0	74.8	2600	.053	.096	840	490	58
4	3022	7+	26	11.8	30.5	73.6	3050	.055	.094	830	570	68
5	3023	5	22½	10.2	30.0	75.0	3000	.056	.096	840	520	61
6	3034	4½	21	9.5	28.7	72.9	2700	.057	.093	720	640	88
7	3031	4½	24	10.9	27.8	62.0	2150	.050	.094	800	320	40
8	3030	7	28	12.7	27.5	62.1	2100	.048	.091	780	480	61
9	3128	7+	27¼	12.6	26.4	60.9	1200	.045	.100	882	340	38
10	3033	5½	26	12.0	26.0	60.5	1550	.050	.094	550	520	94
11	3025	11	24½	11.1	23.0	50.7	2400	.054	.091	630	410	65
12	3130	7+	—	—	23.0	60.4	2550	.063	.100	549	246	44
13	3018	5½	27¼	12.6	20.0	58.4	2200	.066	.083	540	350	64
14	3015	7	27¼	12.6	20.0	57.3	2100	.067	.095	520	340	65
15	3028	8	25¼	11.5	16.5	38.3	1400	.050	.091	395	205	51
16	3027	7+	—	—	15.0	36.4	1200	.055	.098	390	240	61
B. FORWARD-FACING SERIES (—Gx)												
17	3125	7+	—	—	31.0	74.4	3100	.056	.091	755	595	78
18	3126	7+	26	12.0	30.7	74.2	3100	.056	.091	803	732	91
19	3035	6½	25	11.4	22.0	51.0	2950	.053	.089	450	450	100
20	3036	10	27½	12.5	16.5	38.2	1500	.056	.094	330	350	106
C. REARWARD-FACING SERIES (+Gx)												
21	3134	7+	33½	15.2	44.0	88.2	5900	.047	.076	†	†	—
22	3133	7+	28¼	13.0	31.5	74.1	2650	.054	.095	78.5	71.6	91
23	3132	7+	46¼	21.0	23.0	59.1	2300	.051	.088	39.2	43.6	111
24	3131	7+	25½	11.5	22.0	59.9	3000	.065	.100	49.5	32.7	66

*Listed in order of Peak G for each series.

†Connector opened up.

as had been previously predicted.[5]

Forces on the belt in rearward facing deceleration were of course negligible, since the subject was being forced against the seat back and not against the seat itself. Figure 4 shows a comparison of belt loads during 31G impact in each body orientation. Note that the lateral peak loads are reached earlier in the deceleration pattern, 0.070-0.080 seconds after impact, and remain high with a much longer and more gradual slope after decay of the acceleration pattern. On the other hand, the forward-facing belt loads are initiated earlier but reach a peak somewhat later than the laterals, falling off much sooner.

Gross and microscopic necropsies were conducted on all animals except #3130, a 20G lateral impact, within 24 hours post-impact. #3130 survived the impact and was not terminated in order to follow her subsequent progress, which was uneventful. The significant findings of trauma are tabulated in Appendix I.

In the rearward-facing body orientation, all subjects survived the impact but were terminated in order to ascertain any non-lethal trauma incurred. Impacts to 44G were recorded. Despite findings of intracranial hemorrhage in three of the four cases, these injuries were not sufficient to have affected survival. The rearward-facing body orientation, offering good support with widest distribution of force over the body surface, was demonstrated to be by far the most survivable position in this series.

Forward-facing impacts were run from 16.5 to 31G. The most significant findings were pancreatic hemorrhages in every case. Intracranial hemorrhage was again found in each case. This could be a result of the extreme whiplashing of the head as the upper torso jackknifes over the seat belt. This may be more pronounced in this animal than in the human because of the baboon's higher center of gravity. Linear transverse contusions due to the impingement of the lap belt in both lateral and forward facing impacts were marked (Figure 5).

The lateral body position was demonstrated to be by far the most injury-producing of these tests. The combination of lateral flexion of the thorax, plus torquing, places unusual stress on the abdominal and back musculature and viscera. Injuries fell into several categories. Five animals received ruptured bladders, an injury which only occurred in the lateral impacts. Contusions, tears or lacerations, and one complete severance of the uterus also occurred in five cases. In three instances, cervical fractures occurred with complete atlanto-occipital separation and transection of the spinal cord occurring in one 30G impact. Such cervical trauma did not occur in either rear-facing or forward-facing impacts. The most significant finding, and quite unexpected, was that of pancreatic hemorrhage in all lateral cases except two (one survived and was not terminated, and the other, being shipped for autopsy by air express, was lost by the airline and was not in condition to assess upon recovery). Figure 6 shows one case of intralobular hemorrhage typical of this series.

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,® the carcass was held at room temperature for 1½ hours and then packed in ice in a shipping container. A temperature probe was inserted inferior to the lower lobe of the liver and recordings kept. Body temperature of 96.8 F. dropped to 96.2° by 1½ hours, to 64.8° within 14 hours, and to 48° within 24 hours. After 24 hours, gross

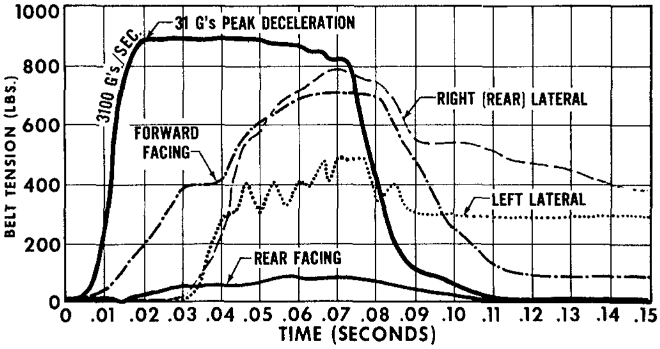

Fig. 4. A comparison of belt loads correlated with deceleration time at 31G (for side, forward, and rear-facing body orientations).

Fig. 5. Typical contusion resulting from impingement of lap belt in impact.

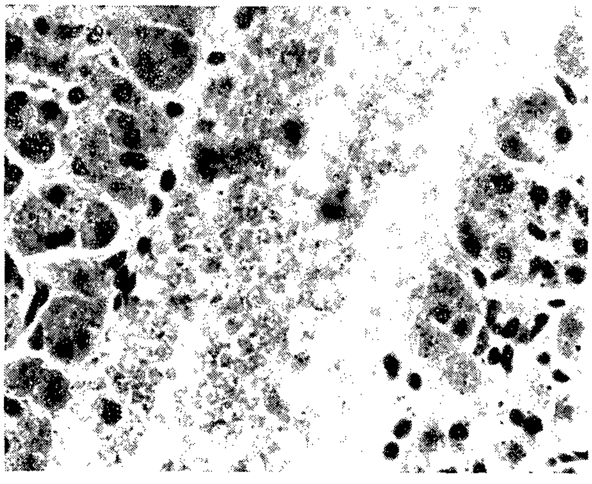

Fig. 6. Intralobular hemorrhage of pancreas of female baboon subject to abrupt deceleration.

necropsy and histopathologic examination revealed mild pancreatic necrosis without hemorrhagic pancreatitis. 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 pancreas of impacted animals, they were considered to be a direct result of the trauma.

The significance of the inter-acinar and inter-lobular hemorrhages observed in the pancreas at necropsy following impact has been carefully considered. A search of the literature, and consultation with other pathologists, while revealing descriptions of pancreatic injury related to dietary excesses, direct trauma resulting from blows over the left upper quadrant of the abdomen, surgical trauma, and reflux from the intestine, has not revealed similar reports of pancreatic injury related to sudden, violent compression and/or displacement of the viscera such as we have found in this series of experiments. We have observed retroperitoneal and inter-lobular hemorrhage grossly, immediately after impact, and these findings 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 intra-lobular ducts which are formed only by the centro-acinous cells with the release and activation of pancreatic enzymes. However, this must still remain speculation until proven, or disproven, by clinical study of survivors.

CONCLUSIONS

The results of this series of experiments suggest the following conclusions:

Rearward-facing impacts were survivable for baboon subjects without irreversible injury up to 44G at over 5800 g/sec onset rate for 0.076 seconds total duration.

Forward-facing impacts typically produced hemorrhages of the meninges and dura at each level of impact tested, from 16.5 to 31G. Pancreatic hemorrhage occurred in each case.

In comparison to either forward ($-G_x$) or rearward ($+G_x$) facing decelerations, sideward-facing impacts ($-G_y$) were found to result in significantly greater injury at every level of impact studied, from 15 to 44G.

Lap belt restraint alone does not provide adequate protection for the side-facing seated occupant. Significant pancreatic hemorrhage and necrosis occurred in impacts as low as 16.5G. This supports a previous study indicating human lateral subjective tolerance levels were at 9G, considerably lower than in either forward- or rearward-facing body orientations.

An unexpected finding was the widespread trauma in the lateral impacts associated with pancreatic hemorrhage. This was determined to be due to impact rather than post-mortem autolysis. Further study of the mechanisms of this injury and apparent effect upon survivability should be made.

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