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Chief, Physical Anthropology Section
Protection and Survival Branch

62-19

FEDERAL AVIATION AGENCY
AVIATION MEDICAL SERVICE
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CIVIL AEROMEDICAL RESEARCH INSTITUTE
OKLAHOMA CITY, OKLAHOMA
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ABSTRACT

Physical, biophysical, and medical data are presented concerning the case of a 20-year-old male of excellent physical condition who jumped from the Golden Gate Bridge in San Francisco, surviving for ten days a free-fall deceleration in the seated position (buttocks to head) of a calculated 4128 g for .0023 seconds. Specific trauma resulting from this impact indicates that this may closely approach the extreme human survival tolerance(s) to impact in this position, and that, while distribution of forces through support of the upper torso may greatly minimize injury to the skeletal system, protection of internal organs will present a much more difficult problem.

INTRODUCTION

Our knowledge of human tolerances to deceleration forces is mainly limited to the range of impact in which non-reversible injury occurs. Although it has long been suspected that man can survive considerably greater forces, qualitative data in the higher ranges has not been available. The following case, one of a large number investigated over the past year, provides some basis for extension of the extreme limit of human survival in the seated position (buttocks to head force) by a factor of over 25 times the known injury threshold.

The objective of this paper is to present the factual data found concerning one human experience in survival of extreme impact forces and to demonstrate that through such studies we may learn considerably more about human impact tolerances and identify more concisely the factors affecting injury and survival. Such knowledge is necessary to establish parameters for design of protective measures to prevent or modify lethal or injurious levels in aircraft crashes, as well as other abrupt impact accidents involving very high g forces. Through such investigations patterns may emerge which may open entirely new approaches to the protection of the body during high decelerative forces.

The method utilized in this investigation is study of human subjects who have been involved in accidental, suicidal, or homicidal (infanticidal) free-falls. For the purpose of this study a free-fall is defined as an unimpeded drop of a body from a known point to a known impact point. Among the factors which must be known are exact height of fall, position of body at impact, clothing or equipment worn during fall which might affect the impact, deformation and condition of impacted object, weather, physical condition of the subject, and any other variable which could have a direct or indirect bearing upon the particular case. While falls from seemingly trivial heights are all too often fatal, the cases generally selected for study are those in which the distance of fall is great and the impacted object is generally concrete, since these present the best data in seeking knowledge concerning extreme survival impact limits. It is contended that such a direct approach is the most realistic means of obtaining information concerning impact trauma and survival conditions and limitations in the ranges above that which human subjects can be voluntarily subjected in the laboratory. Carefully selected cases can often satisfy conditions nearly as rigid as those in an experimental design as far as knowledge of environmental factors is concerned.

Past studies concerned with tolerances to decelerative forces utilizing human subjects have invariably not exceeded the injury threshold limits, which in the seated position (buttocks to head) have varied from 33 g (with rate of onset 50-440 g/sec. at .003-.03 seconds duration)[1] to 95 g (rate of onset of 19,000 g/sec. at .0065 seconds duration)[2] Studies involving animals, anthropomorphic dummies, human cadavers, or theoretical mathematical analog simulations, while providing valuable estimates, can not provide valid data directly applicable to the human in the upper nonreversible trauma limits, i.e., that range between nonreversible injury and death. Extrapolation from studies not involving human subjects is extremely difficult to support and is always open to some question since conclusions, and thus prediction, are based upon variables which, although perhaps similar in certain respects, are not identical.

The following case demonstrates the value, as well as the inherent limitations, of free-fall studies. While the combined data of over 100 free-falls are reported separately[3], it is felt that certain cases such as this one should be considered as an entity due to the nature of these data, and the rather unique circumstances. The hypothesis that this individual landed in a seated position, with legs extended and slightly elevated, and with arms downward, taking most of the initial impact on his buttocks and transmitting sufficient force through his hands and arms to provide support for his body is consistent with both the physical evidence (clothes, descriptions) and medical evidence presented later in this report. This case is thus of particular interest both because of its obvious direct application to aircraft accidents (in which the vertical component of force may be much more severe than the horizontal deceleration), and military and space vehicle application.

DISCUSSION OF THIS CASE

A. ***Environmental Background.*** During the 24 years of its existence, the Golden Gate Bridge across San Francisco Bay has had a tragic record of suicides (237 to date) and accidental falls (at least 85), unmatched by any other over-water structure in the United States. Until this incident, late in 1961, only 1 out of over 300 individuals had survived a fall from this structure. One female still survives, a male (in 1962) died after 2 hours, and the subject of the present study survived for ten days. Since the majority of these falls or leaps ranged from 200 to 250 feet, the fact that an impact of such magnitude was survived even briefly is of considerable scientific interest.

Among the factors which make any Golden Gate Bridge fall so uniquely treacherous when water is impacted are a wind of 5-30 knots, which may turn the body and make maintenance of a vertical attitude virtually impossible, a trough swell to the waves which may reach a 12-foot crest, and a strong tidal current sweeping toward the sea at about 8 knots. Chances of survival of leaps from either approach to the bridge are also diminished by abrupt rocky cliffs, or, as on the south approach, by a large concrete abutment (fender) extending some 300 feet along the base of the bridge.

In the early morning (4:30 AM) darkness of 3 December the subject, a twenty-year old white male in allegedly excellent physical condition vaulted the rail from the east sidewalk of the Sausalito (north) bridge entrance and landed 218 feet below on a roadway at the bottom of a steep cliff. He reportedly stated that he had misjudged the distance, believing it to be only a twenty-foot drop. The jump was observed by two California Highway Patrol officers. The subject was allegedly intoxicated at the time.

FIGURE 1. View from point of jump showing railing and chord of bridge.

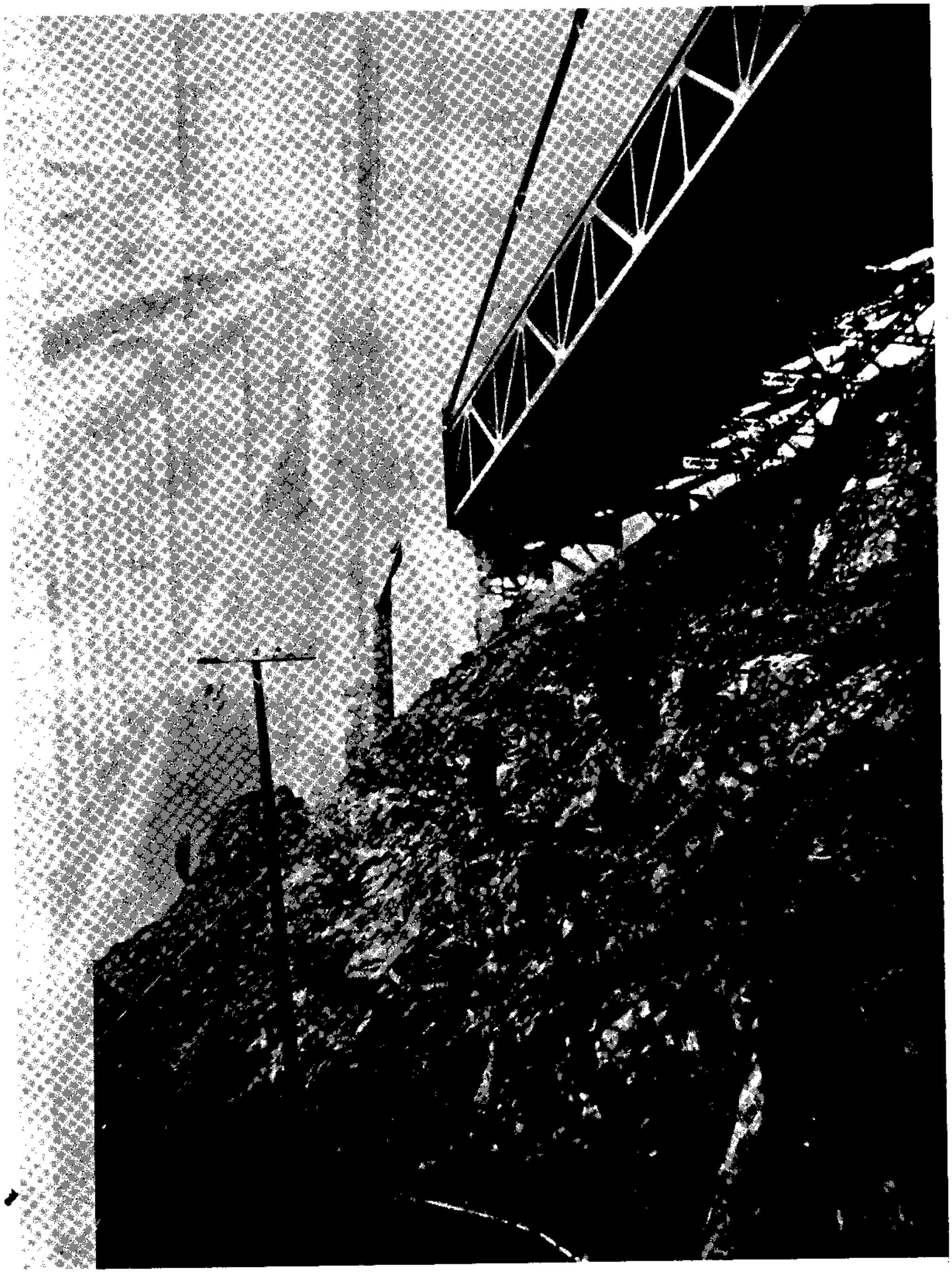

FIGURE 2. View from below and to south. Impact point on far side of telephone pole.

FIGURE 3. View from above showing vertical path of fall and protruding chord of bridge.

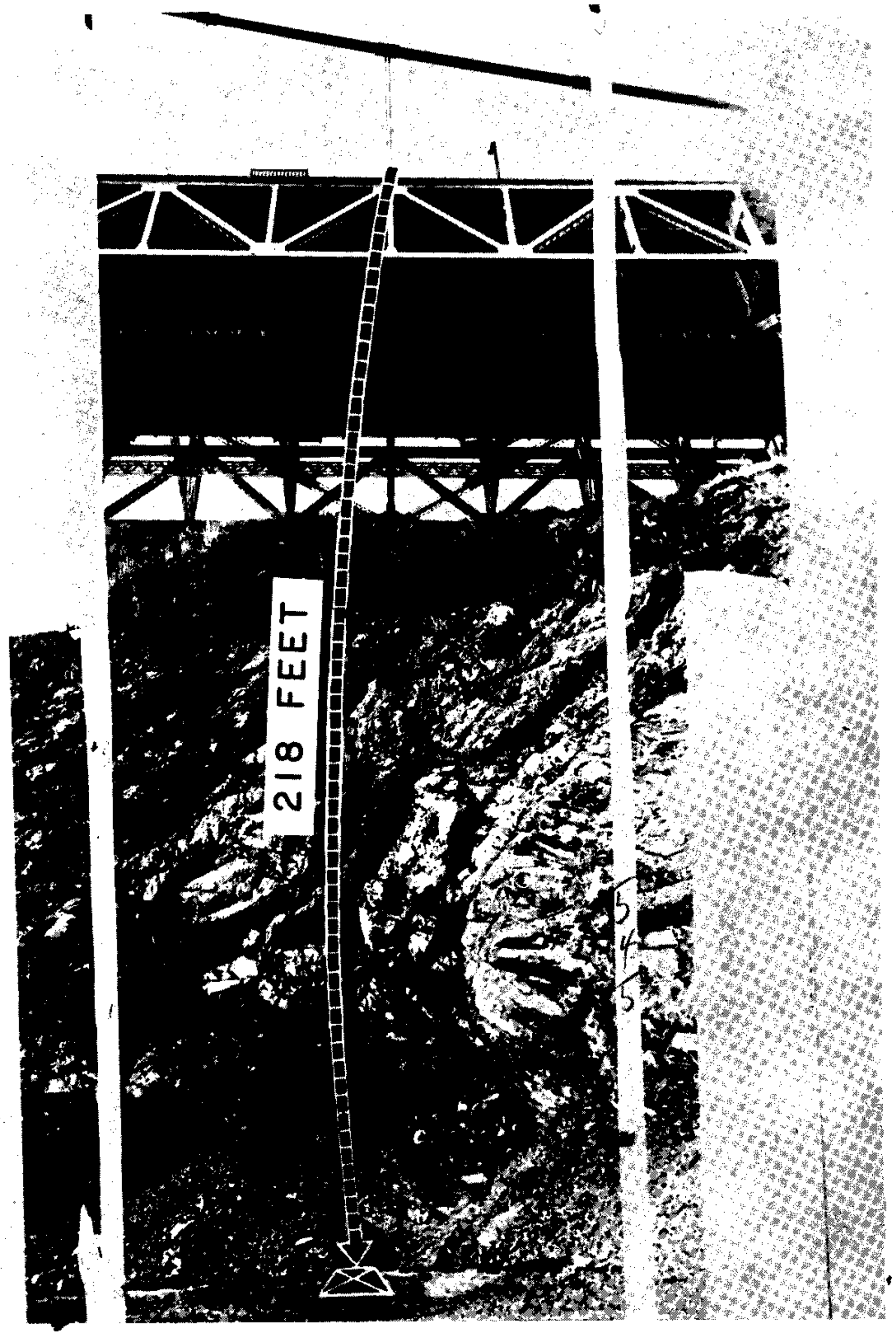

FIGURE 4. Path of fall (photo courtesy San Francisco *Chronicle*).

The railing is four feet above the sidewalk. Eight feet below, extending outwards for four feet, is a flat steel support structure called a chord. The subject, an experienced pole vaulter, was observed to grasp and vault the top railing, striking the chord momentarily on his back. He then rolled off on his left side and fell unimpeded, landing in a seat-first position with his legs extended somewhat upwards. From the chord to the ground is a measured distance of 210 feet. At a point 119 feet below the railing a steep cliff extends some twenty feet out from the vertical, and this cliff was cleared by the subject's parabolic trajectory. The parabolic configuration of this fall is such that it is believed that the cliff could have been cleared (for example, in a similar case occurring from the same structure three months later, in which the subject lived for two hours, the point of impact was 26 feet horizontally from the vertical point of origin). However, except for superficial tears on the back of his coat, a minor laceration on his scalp, and possibly a bruised left arm, no injuries or marks which could be attributed to striking the chord were found. The subject impacted the ground at the point where the steep slope meets the shoulder area of a dirt roadway skirting the bay below. The ground here is rock covered by gravel, dirt, and rock debris fallen from the cliff. A mortuary ambulance was summoned and the attendants were astonished to find the patient conscious and talking somewhat coherently. Figures 1-4 show views of this bridge jump and impact area.

B. ***Description of Clothing.*** Careful examination of the subject's clothing, coupled with the nature and location of injuries received, confirms the opinion that the subject impacted buttocks first. His clothes were submitted to the CARI Physical Anthropology Laboratory and placed on an anthropomorphic dummy of similar body build. Except for a T-shirt and sport shirt which had been washed (although there was reportedly no blood or dirt on either), all clothing was untouched. The subject was wearing a new light-colored top coat, purchased earlier that evening. The ground was slightly damp and there was some vegetation on the slope; however no signs of having hit the cliff were observed on his clothing. Figures 5, 6, and 7 show the location of tears and marks on front and back of the clothing, which correspond well with the location of injuries. At impact, his highly polished shoes were still on his feet with only a small amount of dirt around the edges of the soles. Anteriorly, the only damage to his coat was a 3" puncture-tear of his lower left sleeve with dirt marks extending for 3" above it. Posteriorly, there was a vertical 5" tear below the shoulder on his left sleeve which did not penetrate the inner layer of the coat. This was the site of a severe abrasion and moderate skin laceration. Some 5" below the underarm junction of the sleeve to the coat there was a triangular tear extending 4" horizontally and 2½" vertically, which also did not extend into the inner layer of the coat. A ½" tear below the right scapular area was also superficial. Another tear was found behind the left knee, and he received some knee abrasions. The major physical impact occurred in the seat area, where two distinct tears corresponded with the very severe deep wounds received in this area. The front of the subject's coat was essentially clean; however, the back showed dirt abrasions at several points, which were interrupted in their patterns by creases which indicate that the coat was probably snugged upwards by the wind resistance during his fall.

C. ***Description of Injuries.*** This individual received extensive injuries as a direct result of the impact from the free-fall. Figure 8 summarizes these injuries and combines gross initial examination (abrasions, lacerations); x-ray, laboratory, and surgical findings; final pathology and post mortem; and the reports. The internal traumata and subsequent secondary complications may be regarded as the most serious effects. The patient appeared to be slightly improved until, at 3:00 A.M. on the morning of the 10th day, he suddenly vomited (with a severe aspiration which filled the tracheabronchial tree with gastric contents) and died.

The remarkable thing about this impact is that no significant trauma to either the pelvis or the vertebral column could be demonstrated. Although no lateral x-rays of the lower vertebral column were taken, antero-posterior x-rays of the lumbar and thoracic areas and antero-posterior and lateral x-rays of the cervical area showed no demonstrable fracture,

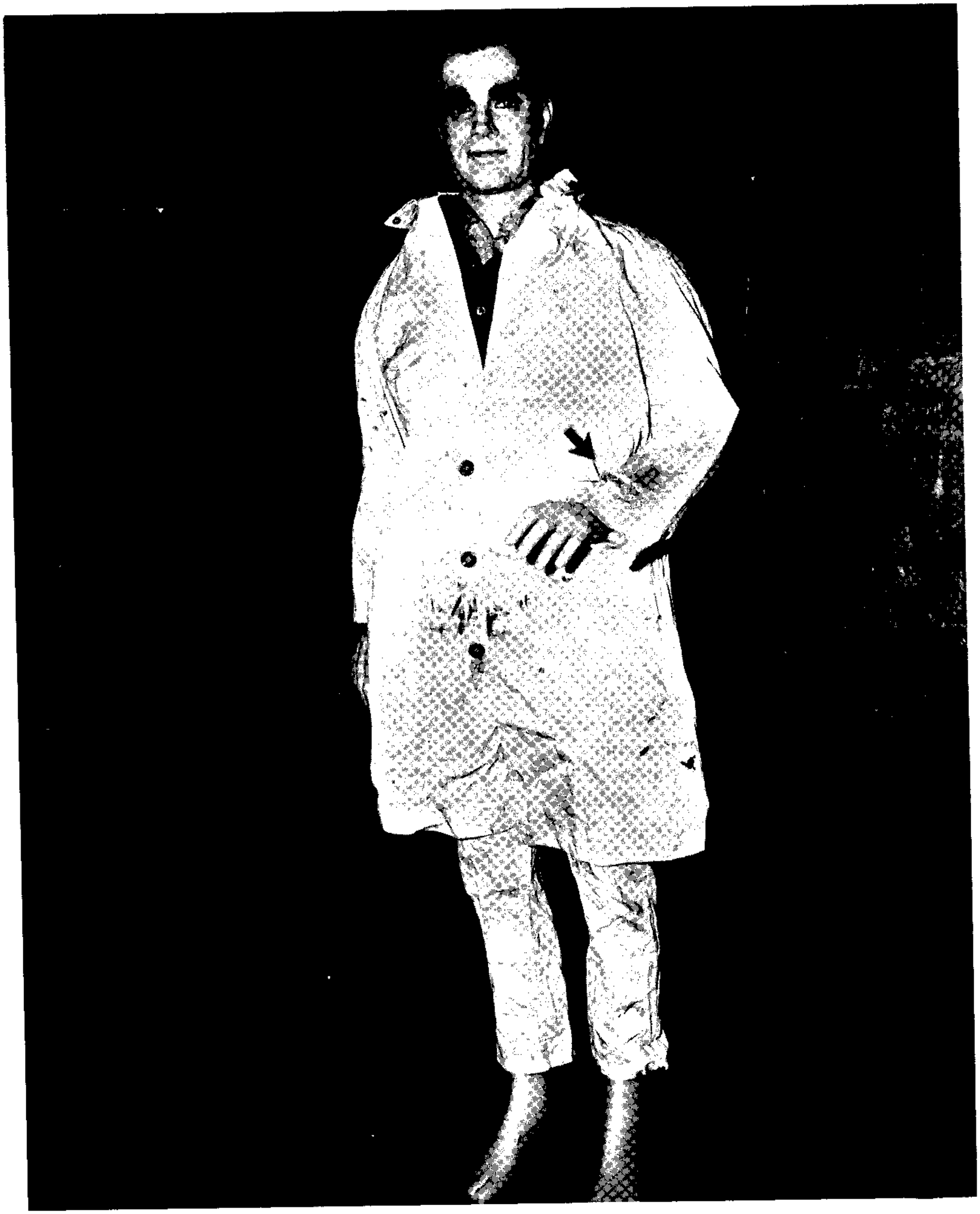

FIGURE 5. Anterior view of dummy dressed in victim's clothing. Note comparative lack of stains or rips except for area of left wrist.

FIGURE 6. Posterior view of dummy. Arrows point to tears in coat. Bottom of coat is not torn, indicating coat was up above victim's buttocks upon impact.

FIGURE 7. Main point of impact on buttocks. This resulted in two severe penetrating wounds.

disc rupture, or displacement of either the vertebral bodies or transverse processes. This is not what would be predicted by projection of the injury patterns observed at 20-30 g's (which result in a high incidence of lumbar compression fractures), as in emergency seat ejection. In this instance the upper body was evidently provided considerable support by the arms at impact. It appears that the arms not only attenuated the force in the body, but supported the upper body sufficiently to provide rather good vertebral alignment and prevent the normal structural trauma to the vertebral column and pelvis. The lower extremities were not involved, and the well developed muscles of the shoulder apparently helped since no demonstrable trauma to the shoulder girdle was found, although it seems likely some torn ligaments may have gone undetected.

A major injury was caused by a sharp rock at the point of initial impact penetrating both buttocks with sufficient force to result in two deep lacerating wounds extending into the ischiorectal fossa, but without perforation of the rectal wall. There were superficial and deep lacerations of the dorsal and volar aspects of both hands, coupled with a comminuted fracture at the base of the left second metacarpal, a comminuted fracture of the distal left radius, as well as a compound fracture of the left radius and severe dislocations of both elbows. Since more trauma was evident on the left side, the left arm may have been slightly more rigid (and probably somewhat behind the center of gravity) upon impact on that side. No trauma of the shoulder girdle was found, thus much of the force absorbed by the arms may have been attenuated before reaching this point.

Among the considerable traumata to internal organs diagnosed or found upon autopsy are the injuries briefly described in Figure 8. A pneumothorax of both lungs with hematoma of the left lower lobe, and approximately 60% collapse of the left lung occurred. A hematuria was associated with a clot in the upper major calyx of the left kidney, located by cystoscopy and retro-grade pyelography and confirmed upon post mortem. The pelvic membrane was found hyperemic but with no large laceration. Several submucosal hemorrhages of the urinary bladder were noted. The pancreas showed some hemorrhage anteriorly with a large amount of fat necrosis in the surrounding tissue. The spleen received a capsular laceration, and the liver received a 3-inch laceration on the posterior aspect of the left lobe.

The pericardium was contused with considerable hemorrhage anteriorly, but without involvement of the visceral pericardium. There was considerable ileus of intestinal obstruction in the abdominal cavity with distention of the small bowel and edema of the wall. There was a 2 cm break in the serosa of the anterior aspect of one of the loops of jejunum. Some hemorrhage was present in the posterior body wall adjacent to the spine at the level of the third to fifth ribs. Although some complaint of pain in neck movement was noted, no evidence of cervical or skull fracture was found.

Thus, internal trauma from the force of this deceleration was quite widespread, rupturing the spleen and liver, with hemorrhages of the pancreas, mediastinum (pericardium) and left renal pelvis, and infarcting the bowel (probably not related to the trauma).

Until more is known about attenuation of forces within the human body, which is complicated by non-linearity of elastic responses, plastic deformation, and damping, (not encountered in homogeneous structures studied by the physicist or engineer) it is possible only to record such traumata in hopes that eventually enough cases spanning the range of impact experience can be evaluated to form better analytic and predictive criteria.

It also must be pointed out that this case had two associated factors which may place it close to the upper range of human tolerance to impact in the seated position: the subject was a young athlete in superb physical condition; and, as has been shown both in laboratory and numerous fall cases studied, inhibition of neuromuscular responses, as in a state of intoxication, does appear to provide a high survival theshold to impact trauma. Previous laboratory impaction of human volunteers in the seated position, for example, have indicated that a 95 g input at the level of the buttocks is attenuated to only 10 g at shoulder level, [2] as the force travels through body tissues, fluids, and structures. This might indicate that in the current instance 2064 g on the buttocks would still result in approximately 250 g at heart level. Although such an extrapolation would still be hypothetical, it does demonstrate that under certain conditions the human body is capable of surviving extreme impact forces much greater than is generally recognized.

D. Biophysical Calculations. Due to the nature of the terrain at this site standard measurement techniques were not useful. A specially designed 250 foot weighted wire tape on a U-control friction reel would not clear the cliff satisfactorily, and attempts to climb from below were not successful. Exact distance of this fall was finally accurately obtained by engineer's transit. Although the total distance of fall was 218 feet, the subject had traveled some 8 feet prior to reaching the chord, and to be conservative in the ensuing calculations it is assumed that he was at zero velocity at the chord level and that the total distance of free-fall is 210 feet from the chord to the impact point.

Velocity in free-fall may be calculated as $V^2 = 2gS$, where g (at San Francisco) = 31.15ft./sec.^{2}, and S = distance. For a free-fall distance of 210 feet the velocity would be 116.2 ft./sec., neglecting air resistance. Air drag estimates [4] indicates a probable velocity at impact of 103 ft./sec. or 70.54 mph (This fall of 210 feet is thus equal to a fall of 172 feet in a vacuum). The ground at point of impact was a hard packed alluvial-gravel mixture on bedrock, and was reported as damp at the time of impact. Examination of the zone of impact indicated negligible deformation of the impacted surface. Hence nearly all of the deformations that occurred during deceleration of the body must have occurred in the body tissues and structures.

Using the "traditional" methods for calculating force in this case, and assuming a very liberal deformation distance of 1 inch, the g force (g = .034 mph/S) would be 2064 g, with rate of onset (RO = 2g/1) of 2,300,608.7 g/sec. for .0023 seconds duration.

However, it should be noted that this assumes a constant force during deceleration, and impact deceleration, particularly of a non-homogeneous body, does not act in this theoretical manner. Assuming the reaction varies linearly with deformation of the yielding reaction surface, the deceleration during impact would also vary linearly and the peak acceleration would be twice the value calculated on the assumption of standard deceleration, or 4128 g. No depression was noted either immediately after the fall or upon subsequent inspection at the site, thus the deceleration distance of the impacted surface may actually have been considerably less than 1 inch, which also would have increased the g force by a high factor. 2064 g may thus be considered in fact a very conservative estimate based upon the available evidence. While this is over ten-times the highest g force previously reported [5] for human survival in any position, it is within the survival envelope of both Von Gierke [6] and Hirsch [7], and we have documented cases in our files exceeding even this force in other positions. Note that the calculated time is of very short duration, but is typical of what we are finding in other ultra-high impact survivals.

Without direct mechanical-electrical measurement of various body tissues at the moment of impact the specific attenuation for any part is difficult to state validly. However, lacking such transducers, we have some evidence of the magnitude, direction, and distribution of forces in this case. As noted, the subject landed on his buttocks, absorbing energy through his gluteal musculature, and secondarily, through his arms to his shoulder girdle and thoracic area.

The dynamic loading, direction, and distribution of forces in the pelvic area may be calculated by x-ray views of the fracture patterns combined with calculated loading. Both ischial tuberosities probably bore the brunt of the initial impact (weight of 90 lbs. (145 lbs. minus wgt. of extremities) × 210 ft.) of 18,900 ft. lbs. of energy, which was, however, attenuated considerably by the gluteal musculature. Since Evans and Lissner [8] (1955) obtained pelvic fractures in dynamic loading of intact pelves subjected to as low as 20 ft. lbs. of energy, the gluteal musculature, particularly of an athlete, as in this case, must be of great importance in energy absorption. Medical rotation of the ischial tuberosities and resulting compressive strain forces upon the public symphysis was sufficient to result in small molecular fractures about both pubes at the level of the pubic symphysis. No separation of the pubic symphysis was found, indicating shear forces were probably not as contributory to these fractures. In

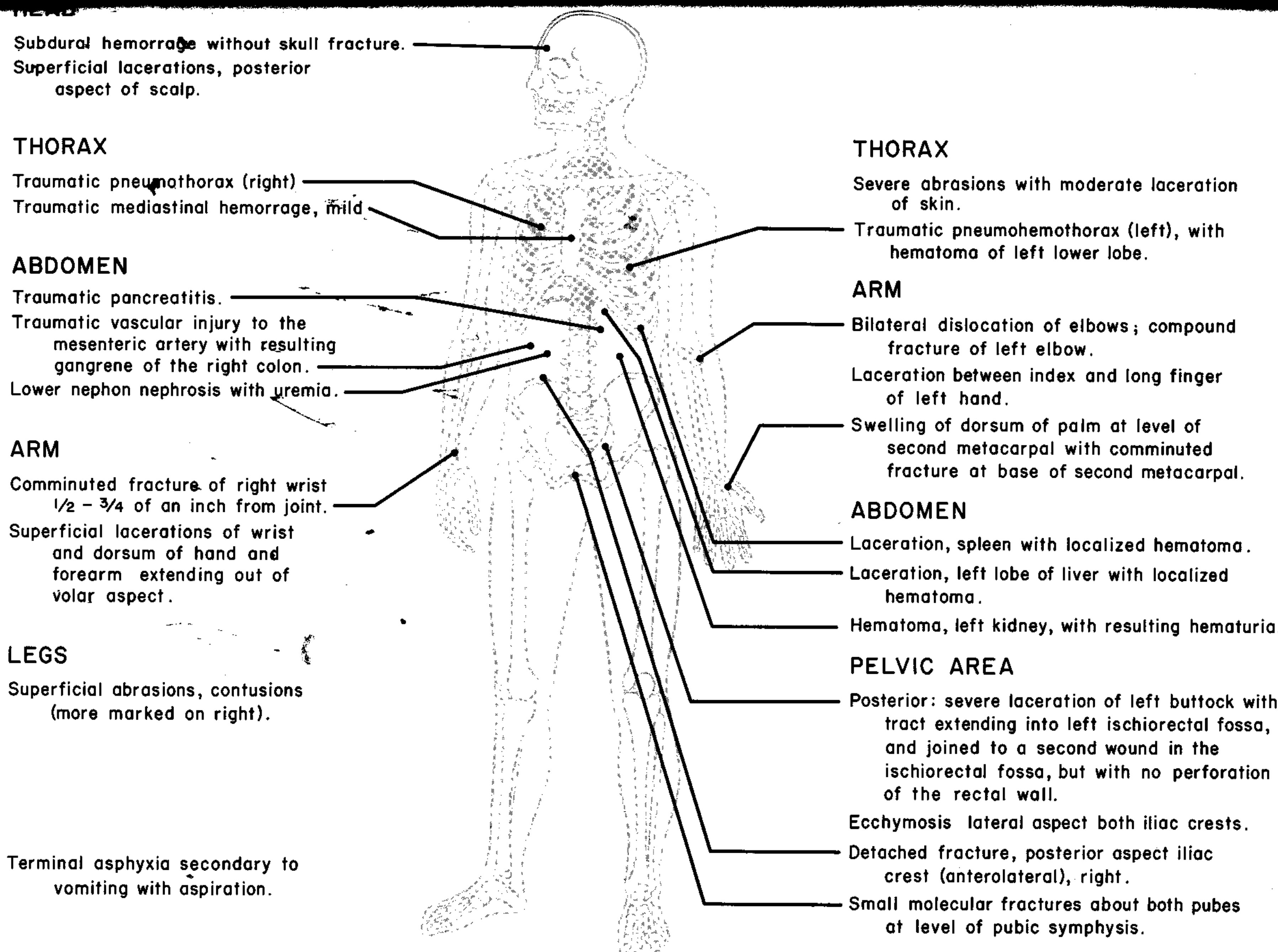

FIGURE 8. Summary of injuries received.

addition the right ilium received a detached fracture of the posterior aspect (antero-lateral) of the iliac crest, possibly caused by medial rotation of the ala and crest of the ilium in response to tensile strain forces. Although it would seem reasonable that the body weight, centered upon the sacrum (due to lack of vertebral compression fractures the vertebral column must have been held fairly vertical at impact) would act somewhat like a wedge in forcing apart the ilia, clinical data is negative concerning this aspect and that of the effects of tensile strain upon the sacroiliac or iliolumbar ligaments.

CONCLUSIONS

Study of instances of human survival of extreme impact forces in which the variables are known or may be validly calculated can contribute valuable data to the fund of knowledge concerning human tolerances to such forces. Cases of accidental falls provide one excellent means of obtaining such information. While free-falls resulting in seated impacts (buttocks to head deceleration) are not common, impacts in this position are of importance because of their direct relationship to vertical force, as sustained in airplane and helicopter crashes. It is not suggested that all individuals could survive an impact of this nature; however, this individual, in apparent good physical condition, did survive the fall itself for an appreciable time. Since we are searching for the upper limits of survivability in order to more realistically establish the entire range of human tolerances, this case is of particular significance.

This case indicates that:

(1) The human survival limits for tolerance to seated (buttocks to head) abrupt deceleration are considerably higher (at least 4128 g assuming linear deformation, for .0023 secs) than the injury threshold (in the range of 40-220 g).

(2) This case supports previous laboratory experiments showing that tolerance to impact force increases with physical condition. Controlled experiments should be done concerning the actual effect of neuro-muscular relaxation due to alcohol or drugs.

(3) Attenuation of force through the gluteal musculature is considerable and suggests that if proper vertical support for the upper torso is available to decrease vertebral loading, seated injury threshold level might be increased.

(4) The time duration of deceleration appears to be a critical factor, and reducing it (for example to .002 secs or less), assuming other factors constant, may also help to increase human tolerance levels.

(5) Extreme impacts in the buttocks-to-head attitude can result in severe injury in internal organs with comparatively minor skeletal trauma. This indicates that protection of internal organs in longitudinal impacts will be a critical problem in increasing human tolerance levels.

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