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BODY ARMOR

MEDICAL ASSESSMENT

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By

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PREFACE

The work described in this report was authorized under LWL Task 30B74, Lightweight Body Armor. This work was started in July 1973 and completed in June 1974. The experimental data are contained in notebook MN 1982.

This project was supported by contract number LEAA-J-IAA-005-4 awarded by the Law Enforcement Assistance Administration, U. S. Department of Justice, under the Omnibus Crime Control and Safe Streets Act of 1968, As Amended. Points of view or opinions stated in this document are those of the author(s) and do not necessarily represent the official position or policies of the U.S. Department of Justice.

In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources – National Research Council.

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Acknowledgments

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A METHOD FOR SOFT BODY ARMOR EVALUATION: MEDICAL ASSESSMENT

I. BACKGROUND.

A. Goat Model Assumptions.

Goat studies have been conducted at several laboratories with regard to blunt and penetrating types of trauma.[1] Several assumptions have been made in order to relate goat organ damage to expected human organ damage. These broad assumptions, at least at Edgewood Arsenal, have been:

1. The 40- to 50-kg goat is a model for a "typical" 70-kg man in body armor studies. The goat is a satisfactory and conservative *model* for studies which include the thorax and the abdomen as targets.

2. The *damage levels of various organs will be similar in* goat and man if the area of impact is equivalent and the same force is applied.

3. The goat experiences the *same natural course of disease* as would the human after similar injury.

4. The 70-kg human, with thicker and more resistant abdominal and chest walls, would incur no more damage than would the goat from a given impact. Because of the increased body wall protection, the *human would probably incur even less damage.*

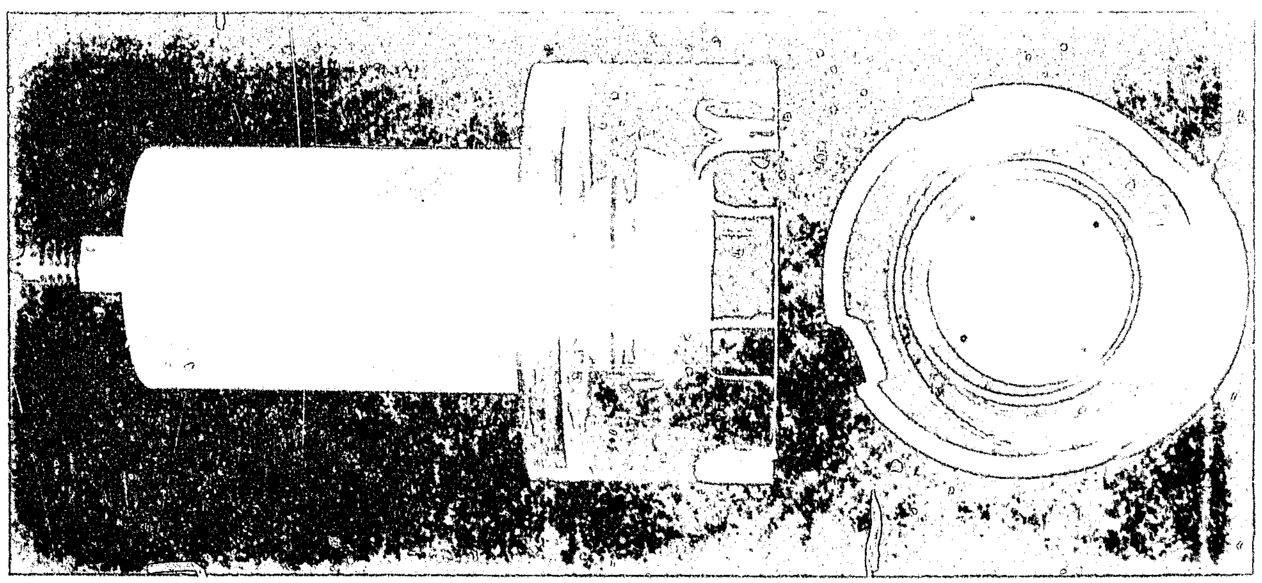
Since the present project depends upon the accuracy of some of these assumptions, *what objective evidence exists that the goat is a* satisfactory model? Prior ballistic projects have utilized subjective medical evaluation based upon the judgment of a surgeon(s) and pathologist(s). Those physicians have examined the damaged organ(s) and assumed that similar damage would occur in a human. For the purpose of weapon development, they have also subjectively evaluated the lethality of the animal injury and immediate incapacitation in different time frames and scenarios.[2]

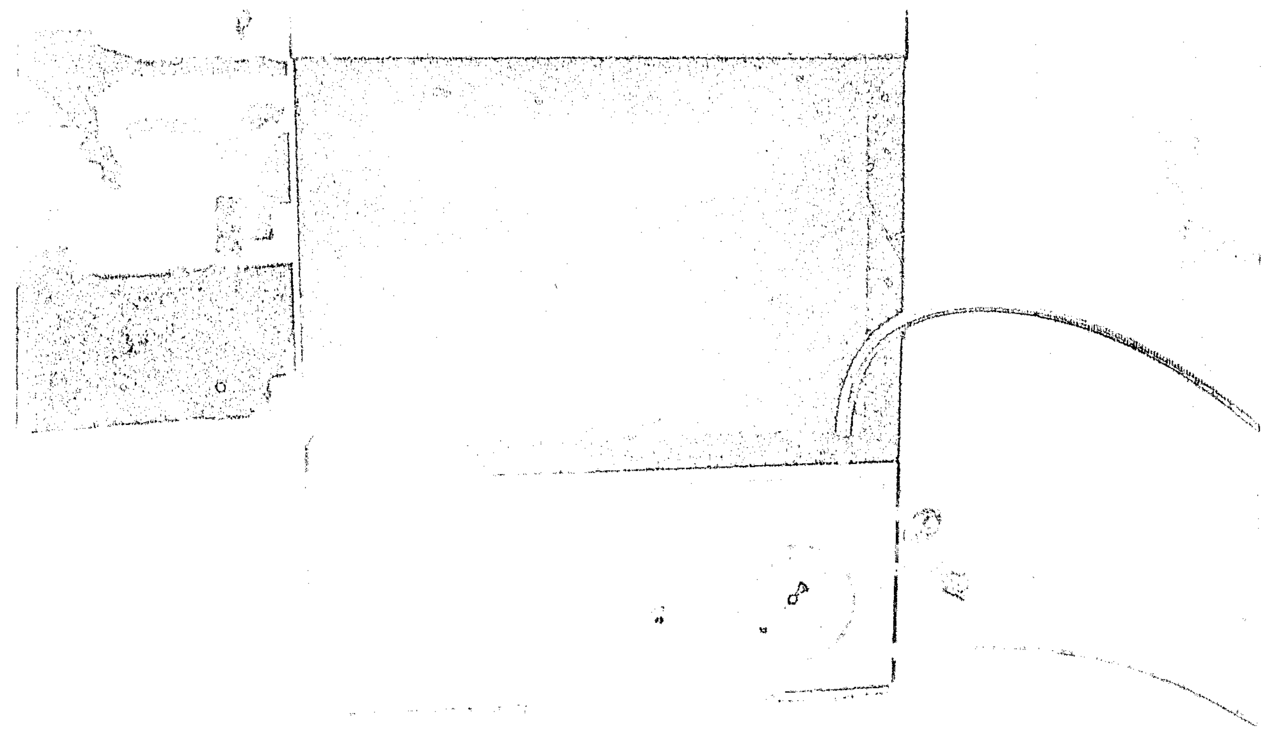
Most ballistic work with the goat has involved penetrating wounds of the thorax and/or abdomen. Evidence that severe penetrating injuries are somewhat similar in the goat and in the human has been borne out by masses of human autopsy data where missiles have been recovered.[3] The mechanism of *blunt trauma* injury registered through soft body armor is different, however, from penetrating injury. The blunt trauma injury incurred behind a bullet-proof vest is due to the force of the missile hitting the vest. This force *deforms the body wall* which impacts the underlying viscera. *Penetrating missiles*, on the other hand, cause damage by creating a hole in various tissues (permanent cavity) and a surrounding *temporary cavity*. The size of the temporary cavity, which is a momentary displacement of structures in the path of the missile, can vary from a 1-cm diameter with a .22 caliber bullet through the liver to a 30-cm diameter with the M16.[4-6]

No unified body armor test plan with bullets impacting flexible body armor had been devised previous to this effort. The entire study incorporates goat-human correlations, as well as parameters such as fabric denier and weave, bullet velocity, energy, shape, weight, range, "backface signatures," and deformation of armor studies; and a mathematical model for future garment evaluation. This report, however, is concerned primarily with the assessment of goat damage and an *evaluation method for goat-human correlation*.

B. Goat Model Discrepancies.

There are certain discrepancies that exist between the goat and the human relative to body armor or missile testing.





the organs used had been damaged by a previous impact. Some studies were conducted immediately after death, and the others were conducted after the organs had been refrigerated for 24 hours.

Approximately 24 hours after death, lungs, livers, kidneys, and spleens from eight men were tested at the Office of the Chief Medical Examiner of the City of New York. The average age of the decedents was about 40 years, and the average weight was about 70 kg.

It was possible to test each uninflated goat lung in three different areas, each liver in four, each spleen in two, and each kidney in one. As the human organs (except for the spleen) are considerably larger than the goat's, more trials of most organs were possible. Each of 16 atelectatic lungs was tested in four different areas, each kidney in two, each liver in five, and each spleen in one.

B. Results.

The average depth of penetration of the water jets into each organ and the number of trials are listed in table 1. The uninflated, refrigerated lung was most easily penetrated, with an average of 3 ±1 cm (figure 3). These 20 lungs were essentially collapsed at the time of testing. The water jet penetrated the full thickness of the spleen which was 1.5 ±0.5 cm (figure 4). Tests on the kidney with intact capsule revealed holes 0.6 ±0.3 cm deep in 20 trials (figure 5). Liver penetration results were 0.5 ±0.3 cm in 40 trials (figure 6).

Table 1. Average Depth of Penetration of Water Jet in Goat and Human Organs

Organ	Depth of penetration (cm)					
	Goat (10) Depth, SD	Trials	Human (8) Depth, SD	Trials	Goat (10) Depth, SD	Trials
	At 24-hr postmortem		At 24-hr postmortem		Immediate postmortem	
Lung*	3 ±1	60	3 ±1	64	1.72 ±1.08	15
Spleen	1.5 ±0.5	10	1.5 ±0.5	8	2.1 ±0.2	12
Kidneys	0.6 ±0.3	20	0.2 ±0.1	32	0.6 ±0.18	11
Liver	0.5 ±0.3	40	0.2 ±0.2	40	0.97 ±0.82	34

* Uninflated.

Figure 3. Goat Lung Cross Section
(Arrows point to linear excavation.)

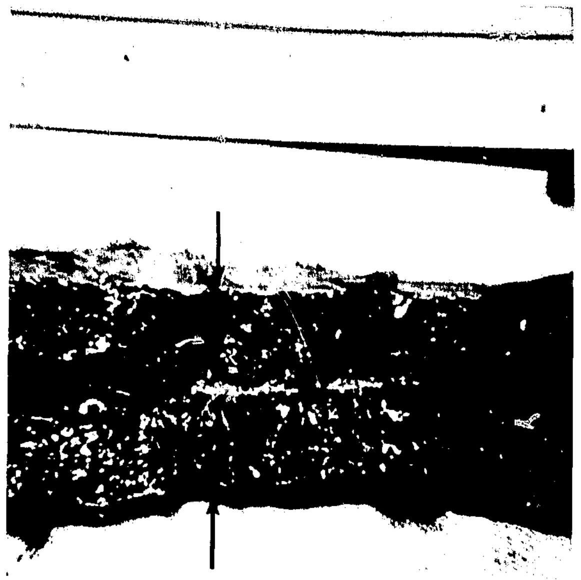


Figure 4. Goat Spleen – Two Adjacent Cross Sections
(Arrows point to entrance holes which penetrate through the full thickness of the spleen.)

Figure 5. Goat Kidney
(Arrow points to one of four parenchymal penetrations.)

Figure 6. Goat Liver Cross Section
(Arrow points to entrance hole of a penetration.)

Results with the goat organs tested immediately after excision were essentially the same as those with the refrigerated organs except that the lung was more resistant to penetration. In the human lungs, the average hole depth, 3 ±1 cm, was the same as that of the goat (figure 7). The spleen was similar in size to that of the goat, and again the water jet penetrated the full thickness of the spleen, averaging 1.5 ±0.5 cm in the eight tests. In no trial of the kidney, however, was the parenchyma penetrated even in those instances where the capsule was entered (figure 8). This indicated that the *human kidney is more resistant* than the goat kidney to this water jet trauma. The human liver had notches in the capsule averaging about 0.2 cm, but there was no penetration into the liver parenchyma as occurred with the goat liver. *The human liver, therefore, appeared more resistant to penetration* than the goat liver (figure 9).

Figure 7. Human Lung Cross Section
(Arrows indicate entrance hole and linear excavation.)

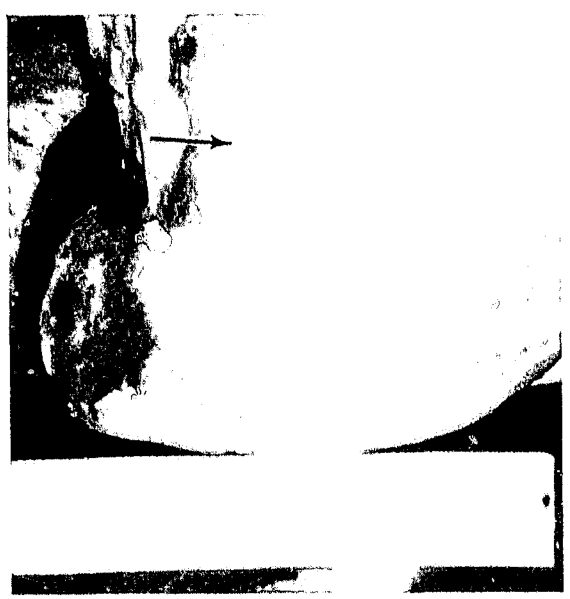


Figure 8. Human Kidney
(Arrow points to one of four indentations in kidney capsule.)

Figure 9. Human Liver – Dorsal Aspect
(Arrow points to one of four indentations in hepatic capsule.)

C. Discussion.

It should be stressed that no attempt was made to state exactly how much more or how much less resistant the goat organs were compared to those of the human. The object was to determine only whether the goat organs were more or less resistant and, therefore, whether the human would incur more or less damage. The water jet stream trauma as standardized in this experiment permits certain conclusions. The collapsed *goat and human lung and the goat and human spleen reacted similarly.*

Tests revealed that the *goat kidney and liver are less resistant to trauma* than are the human counterparts. Damage to those organs should be greater than that which would occur from a similar impact over the human liver or kidney.

Because the human chest and abdominal walls are about twice as thick as the goat's, the human would probably incur even less damage than the goat. A 70-kg man has about a 6-cm-thick chest wall and a 4-cm-thick abdominal wall in the mid-clavicular line. One could argue that although the goat body wall is thinner, it is more resistant than the human body wall. This is unlikely, since all layers of the goat wall are thinner. Specific tensile strength testing, however, has not been performed.

III. COAGULATION STUDIES IN THE GOAT.

When our initial efforts in testing and evaluating blunt trauma effects in the goat were begun, it was noted that goat blood had a tendency to clot indwelling catheters in both arteries and veins despite heparin irrigation. We noted that certain thoracic hits in the goat produced a small lung contusion (hemorrhage in lung parenchyma). We then tried to determine whether this small volume of contusion was well localized by a quick and efficient coagulation system. If the goat coagulation system differed to any great extent from that of the human, the goat could not be considered a fair test animal to compare with man with respect to blunt trauma.

Of all bleeding parameters which could be measured, the partial thromboplastin time (PTT) and prothrombin time (PT) were chosen. These parameters measure the intrinsic and extrinsic coagulation system, and should reveal major discrepancies between the two species.[8] Eight animals were tested and the results indicated that the goat and the human have similar values (table 2). Wintrobe[8] gives the normal PTT for humans as 30 to 45 seconds and the normal PT as 11 to 16 seconds. Our studies indicated that normal goat PT and PTT in seconds were 11.9 ±0.7 and 35.4 ±4.9. Dorner and Bass[9] reported goat results for PT and PTT to be 11.1 ±0.82 and 40.8 ±6.39. Further tests to determine how the goat and human coagulation systems differ are highly sophisticated and must be performed under the guidance of a hematologist.

Table 2. Studies of Partial Thromboplastin Times and Prothrombin Times in the Goat

Normal human value	Partial thromboplastin time (PTT)	Prothrombin time (PT)
Goat	30 to 45 seconds	11 to 16 seconds
1	24.6	12.7
2	35.6	11.4
3	37.4	11.9
4	30.4	12.4
5	39.6	11.4
6	35.2	12.9
7	34.4	11.5
8	38.9	10.9
Goat average and standard deviation	35.5 ±4.9	11.9 ±0.7

IV. GARMENT TESTING WITH .38 CALIBER BULLET.

All bullets fired in this group of anesthetized, intubated animals were .38 caliber at a velocity of about 800 fps. All the armor samples were 7-ply, 14-inch squares of Kevlar,* secured over the target area with straps. Unless otherwise indicated, the animals were in a standing position.

A. Goat Heart Impact.

1. Methods.

Another problem with regard to the goat model has to do with aiming. It initially appeared difficult to aim at the acutely angled area over the goat sternum in order to impact the underlying heart.

Two experiments have been performed with the goat in a sitting position in a rack covered with the protective garment. The anesthetized, intubated animals were monitored with electrocardiogram (EKG) limb leads. The target was the point of maximum impulse located about 12 cm anterior from the xiphoid over the sternum. Control and post-impact tracings were recorded up to 1 hour.

2. Results.

There were EKG changes that revealed possible heart damage. Animals were sacrificed at 24 hours by pentobarbital overdose. Autopsy results showed a 1.5-cm hole through the subcutaneous tissue and overlying muscle. There was no damage to the sternum. In both cases there were diffuse subendocardial ecchymoses (0.2 to 0.5 cm) on the inner surface of the left ventricle, most numerous over the papillary muscle. The lesions were less than 1 mm deep.

3. Discussion.

Nieberle[10] claims that subendocardial ecchymoses are frequent in Kosher slaughtered animals and are due to persistent beating of the empty heart after rapid exsanguination. Light *et al.*[11] have reported this finding in 22% of 514 goats that have incurred various types of trauma. These animals either died from wounds or were sacrificed after surviving wounding for 48 hours. The trauma was not directed at the heart in these cases. Smith and Tomlinson[12] found subendocardial hemorrhages in 29 out of 235 human patients with fatal intracranial disease, an incidence of 12%. In 607 autopsies on patients without fatal intracranial disease they found only three cases of subendocardial hemorrhage, all in persons who were not the victims of mechanical trauma. More experiments are planned to make certain that this phenomenon is not directly related to the blunt trauma. There will be additional heart impacts in the intercostal space, with the goat in a standing position, to determine damage levels without the protection of the sternum (which the human would have). A group of animals will be shot and sacrificed 24 hours later; another group will be kept 4 weeks to follow any possible delayed heart damage. Cardiac outputs, enzymes, EKG's, and left-ventricular end diastolic pressures will be monitored at intervals.

B. Goat Spinal Impacts.

Four impacts into Kevlar over the goat spine created holes in the skin and subcutaneous tissues and fractured the spinous processes (figure 10). Three paraspinal shots broke off portions of the transverse processes. No injury to the lamina was observed in any case. No spinal cord injury was found upon gross or histological examination. Three of the animals had weak hind legs upon recovering from anesthesia, but they were fully ambulatory 48 hours after shooting. Our neurosurgical consultant noted that the spinous processes are significantly larger in the goat than in the human and, therefore, offer the goat more protection from this type of trauma. Though only weakness of the hind legs were noted in 2 goats, he feels that an impact over the spine in the human might cause immediate weakness and even contusion of the spinal cord. To more accurately predict the consequences of a human spinal impact, another species with a spine similar to a human could be used. Since chimpanzees are an endangered species, this phase of the project seems limited.

* Kevlar 29 material (E. I. DuPont de Nemours & Company, Wilmington, Delaware). Warp-400 denier, 267 filaments, 2-ply, 4 twists/inch, z direction for both longitudinal and filling; weave – plain; ends/inch – 38 ±2; picks/inch – 38 ±2; weight – 8.0 oz/sq yd; thickness – approximately 0.015 inch.

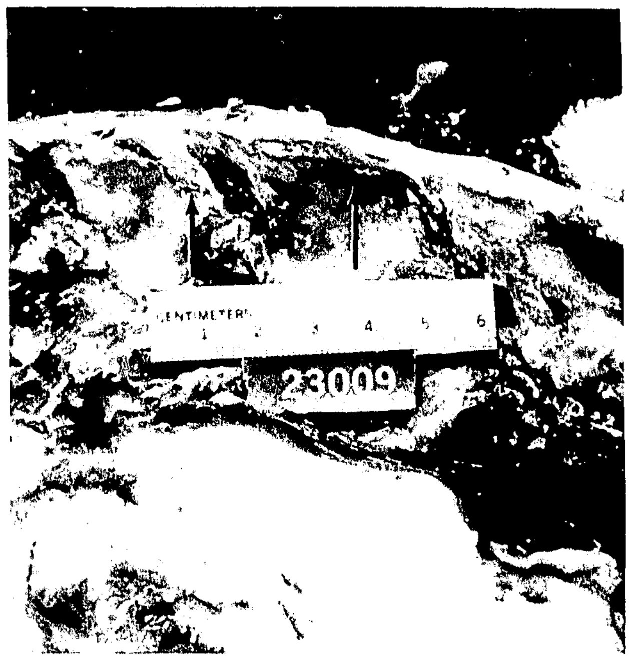


Figure 10. Dissected Goat Spine with Arrows Indicating a Linear Fracture of Two Spinous Processes

C. Goat Lung Impacts.

1. Kevlar-Protected Goats.

a. Methods.

The target in these 14 goats was the left fifth intercostal space about 12 inches from the dorsal midline with the left leg held in extension. Arterial blood gases were monitored before impact and 15, 30, 45, 60 minutes, and 24 hours after impact. The average velocity of the bullet was 808.9 ±12.4 fps. All goats were sacrificed at 24 hours and autopsied. Lung contusions were measured by determining the length, width, and depth of the hemorrhagic area.

b. Results.

Ten of the goats incurred lacerations extending to the rib. Goats 4, 7, 11, and 14 had only skin contusions. The average maximum increase in respiratory index (RI) over 24 hours in the 14 goats was 0.08 ±0.07 (all RI's returned to normal within 24 hours), and the associated average lung contusion was 5 ±12 cc (table 3). The largest contusion was 45 cc, which would be of little clinical significance in a human (figure 11). The low increases in RI allowed us to predict that there would be less than a 100-cc lung contusion in every case. The injuries to the skin, subcutaneous tissue, and muscle would present minor medical problems. Treatment of the lacerations would usually involve only cleansing and dressing the wound.

The impact might cause a rib fracture (as occurred in three goats: 2, 6, 9), but there was no associated pneumothorax or hemothorax (figure 12). A human with a rib fracture and minor lung contusion should not be incapacitated at the time of injury and, under stress and well motivated, might only feel minimal discomfort. When the stressful period subsided the patient would still be able to walk into a hospital.

Table 3. Respiratory Index Increase Related to Cubic Centimeters of Lung Contusion in Goats with Protective Body Armor over Thorax

Goat number	Respiratory index control value	Respiratory index increase from control value*	Size of lung contusion	Velocity
			cc	fps
1 - 23025	0.26	0	45	823
2- 23023	0.54	0	8	804
3 - 23027	0.15	0	1	810
4 - 21650	0.41	0	1	807
5 - 23015	0.39	0.03	0	781
6 - 23022	0.25	0.03	1	801
7 - 21647	0.45	0.08	1	795
8 - 23028	0.22	0.09	0	810
9 - 23016	0.21	0.09	11	823
10 - 21648	0.49	0.13	3	817
11 - 23019	0.31	0.13	0	823
12 - 23026	0.24	0.13	0	820
13 - 21649	0.21	0.18	1	813
14 - 23020	0.23	0.18	0	797
Mean and standard deviation	0.31 ±0.12	0.08 ±0.07	5 ±12	808.9 ±12.4

* Maximum increase in the 24-hour observation period.

Figure 11. Goat Lung *In Situ* (Post Mortem) with 45 cc Contusion

(This was the worst lung damage of the 14 animals tested.)

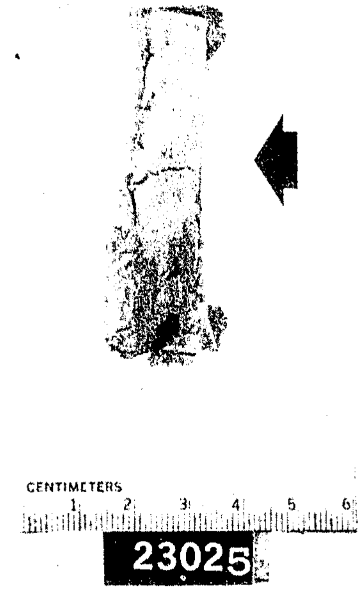


Figure 12. Goat Rib with Arrow Pointing to a Transverse Nondisplaced Fracture

2. **Comparison of Earlier Studies of Riot Control Weapons and Other Types of Body Armor with Present Studies of Kevlar-Protected Goats.**

a. **Methods.**

During the past 3 years, other studies of the effects of impacts of various missiles on the goat have been performed at Edgewood Arsenal. These have included thoracic impacts of riot control weapons and bullet impacts against body armor (usually 12-ply ballistic nylon). In these studies of intubated, anesthetized goats, blood was drawn before impact and 15, 30, 45, and 60 minutes after impact for measurement of blood gases. All the goats had been autopsied 24 hours after impact and lung contusions measured.

We used the data on 67 goats from riot control weapon studies and 31 from body armor studies that had not sustained a penetrating impact of the chest. We compared the RI's and sizes of lung contusions with those sustained by our Kevlar-protected goats shot with the .38 caliber bullet.

b. **Results.**

Table 4 contains the data from the retrospective study. The animals are grouped according to maximum increase in RI over control 1 hour after impact. The first grouping in which goats died (3/6) was an RI increase of 0.51 to 0.6, and the average size of the lung contusions in the six goats was 161 cc. The Kevlar-protected goats (table 3) had an average maximum increase in RI of only 0.08 and an average of 5 cc of lung contusion, the largest individual contusion measuring 45 cc. Based on this comparison, it is unlikely that the amount of damage sustained by the Kevlar-protected goats would be of any serious consequence whether it occurred in the goat or in man.

Table 4. Relationship Between Respiratory Index Increase from Control, Cubic Centimeters of Lung Contusion, and Death or Survival

Respiratory index increase from control	Cubic centimeters of lung contusion and standard deviation	Mortality fraction	Cubic centimeters of lung contusion in animals that died
0	14 ±18	0/11	
0.01 - 0.1	25 ±32	0/21	
0.11 - 0.2	40 ±48	0/15	
0.21 - 0.3	107 ±69	0/7	
0.31 - 0.4	107 ±82	0/8	
0.41 - 0.5	141 ±101	0/8	
0.51 - 0.6	161 ±149	3/6	150, 346, 391
0.81 - 0.9	235 ±200	1/6	567
0.91 - 1.0	398 ±38	0/4	
1.01 - 2.0	450 ±98	2/5	550, 459
2.01 - 11.1	312 ±122	7/7	392, 258, 168, 421 144, 363, 441
		98	358 ±141 (average contusion in group that died)

3. Correlation of Lung Damage in Goats and Humans.

In another retrospective study, the RI was investigated in a group of 177 consecutive intubated patients at the Maryland Institute for Emergency Medicine.[13] A more detailed analysis of that group of patients revealed a total of 52 that incurred thoracic injury alone or in conjunction with other trauma. Any case where head trauma was also present and was the cause of death was not considered. Of the chest trauma group there were 11 (21%) patients that died and 41 (79%) that lived (table 5). The number of patients in each category are grouped by their RI's in table 5. No patient that survived had an RI of more than 7. Only one patient died with an RI less than 4.0, and that was 3.86. Table 6 correlates the probability of survival with various peak RI ranges.

In this project one assumes that if a human were wearing a bullet-proof garment and were impacted over the chest wall, he would be treated at a hospital within 1 hour.[1] If the damage to the lung, that is, a lung contusion, does not increase his RI above 4, he should have a 96.5% probability of survival. As in the goat, the maximum total (unaveraged control + increase) RI was 0.72 and the averaged total of the 14 goats was 0.39. These figures are far from the 4.0 limit which can apparently be tolerated in the treated human; therefore, the lung damage levels in the injured, Kevlar-protected human would not be a serious risk and would require nonoperative treatment.[14]

D. Goat Liver Impacts.

Seven central impacts over the liver (targeted on the 11th intercostal space on the mid-right side) caused contusions averaging 50 cc. There was no more than 100 cc blood loss in any case. (See figures 13 and 14.)

Table 5. Patients with Thoracic Injury

Respiratory index	Number of patients that lived	Number of patients that died
0 - 1	8	0
1.1 - 2	5	0
2.1 - 3	8	0
3.1 - 4	6	1
4.1 - 5	7	1
5.1 - 6	6	2
6.1 - 7	1	0
7.1 - 8	0	3
8.1 - 9	0	2
9 - 13	0	2
Totals	41 (79%)	11 (21%)

Table 6. Probability of Survival and Respiratory Index

Respiratory index range	Probability of survival (P_s)
	%
0 - 4	96.5
4.1 - 6	81.4
>6	12.4

Figure 13. Goat Liver *in Situ* (Post Mortem) with Typical Liver Laceration

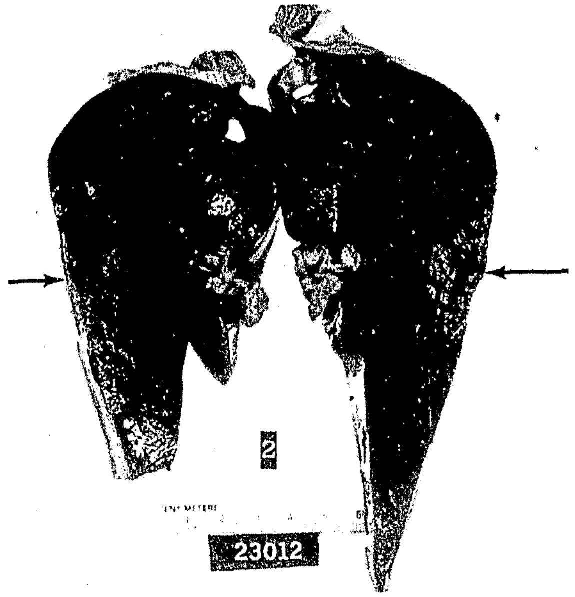


Figure 14. Goat Liver Cross Sections with Arrows Pointing to Lesions

This injury in the human would also cause intraperitoneal bleeding as well as abdominal pain, tenderness, and muscle rigidity. The victim would probably not be immediately incapacitated, and presumably the patient would be admitted to the hospital within 1 hour after injury. If an abdominal paracentesis were indicated, and it was positive for free blood, surgery would be performed.[15] The liver wound is a minor one and can be handled with a *surgical mortality (death within 30 days of surgery) under 5%.*[16] This should be compared to a central liver wound incurred without the jacket that would incapacitate immediately, and would carry an operative mortality as high as 60%.

E. Goat Gut Impacts.

The data infer that if the stomach, small or large intestine, under an area of impact is markedly dilated with air, the bullet force transmitted through the jacket could cause a perforation. Under anesthesia, the goat consistently develops dilatation of the rumen. Perforation of this viscus by the .38 caliber bullet through the 7-ply Kevlar occurred 50% of the time (four out of eight shots) (figure 15). When a portion of gut that *was not dilated was impacted (eight times), perforation did not occur.* Only a serosal contusion was registered with occasional minimal mucosal contusion.

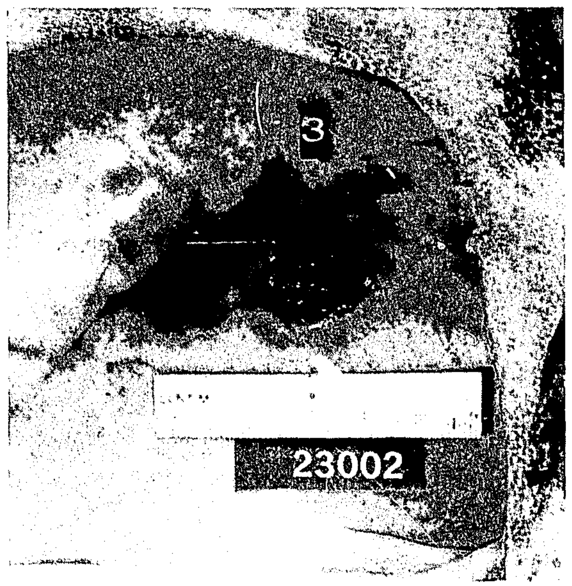


Figure 15. Goat Rumen *In Situ* (Post Mortem) with Arrow Indicating a Small Sealed Perforation at the Superior Margin of a Punched Out Serosal Injury

Any perforation with sugical intervention within 6 hours after injury should have a *surgical mortality rate under 5%.*[17] The viscus that is *only contused would require no operative treatment* in almost all cases.

F. Goat Spleen Impacts.

Impacts over the spleen were difficult in that the spleen was an elusive target. In addition to being a relatively small organ, its orientation and location in the goat is variable enough so that it is hard to hit centrally with consistency. Three attempts were made, and in one shot there was no damage to the spleen; in another there was a 2-cm contusion at the inferior border; and in the last round the spleen was missed.

Since the spleen is easily damaged, we expect that a direct hit over the spleen in the human would probably cause at least a contusion or intracapsular hematoma. Both of these lesions would eventually require surgery, and the surgical mortality should be under 5%.[18]

V. DEFINITIONS OF GARMENT PROTECTION AND ORGAN VULNERABILITY.

According to Montanarelli, *et al.*,[1] a protective garment should have the following capabilities with regard to the present project. In this experiment the two missiles are the *.22 caliber bullet at 1000 fps and the .38 caliber bullet at 800 fps.*

1. It should *prevent penetration by the bullet* into the chest, abdomen, or back.

2. Any blunt trauma effects should have *a mortality risk of 10% or less.*

3. An adult male wearing the garment should be *able to walk* from the site of a shooting after being hit in the chest or abdomen by a bullet of specified caliber or weight and velocity.

It is assumed that the patient will receive *medical attention at a hospital within 1 hour.*

Suppose that a jacket is meant to cover and protect the thorax, abdomen, and back, as in the accompanying four diagrams (figure 16 through 19). The areas that are outlined represent the organs that will register damage that would probably require surgery or result in intensive care monitoring if covered by a new 7-ply Kevlar jacket and impacted with a .38 caliber bullet. Vulnerability then, with regard to body armor, should perhaps refer to that area of the body that will require surgery or intensive care even if the overlying body armor prevents penetration of the particular missile fired. The frontal view (figure 16) indicates that the liver and spleen are vulnerable. The area of the heart is also probably vulnerable, and this will be tested further in the goat. The right lateral view (figure 18) illustrates the large area occupied by the liver and the small area occupied by the right kidney. It should be noted here that the location of goat kidneys is variable, and they are small targets. Renal contusions, however, are usually managed conservatively and rarely is surgery necessary. Since a patient with a renal contusion would have hematuria, he would be hospitalized and followed closely for signs of blood loss. The left lateral view (figure 17) demonstrates the vulnerable kidneys, spleen, and heart.

The percentage of vulnerable area will vary according to the design of the protective garment. Based on earlier testing, the number of layers of flexible Kevlar necessary to convert most of the vulnerable areas into totally invulnerable areas would probably be too heavy to incorporate into a garment that would be comfortable enough for routine use.

A. Method to Determine Mortality with and without Body Armor.

In order to answer the problem as to the mortality probability after being shot with a .38 caliber bullet with and without the protective garment, the following method was used:

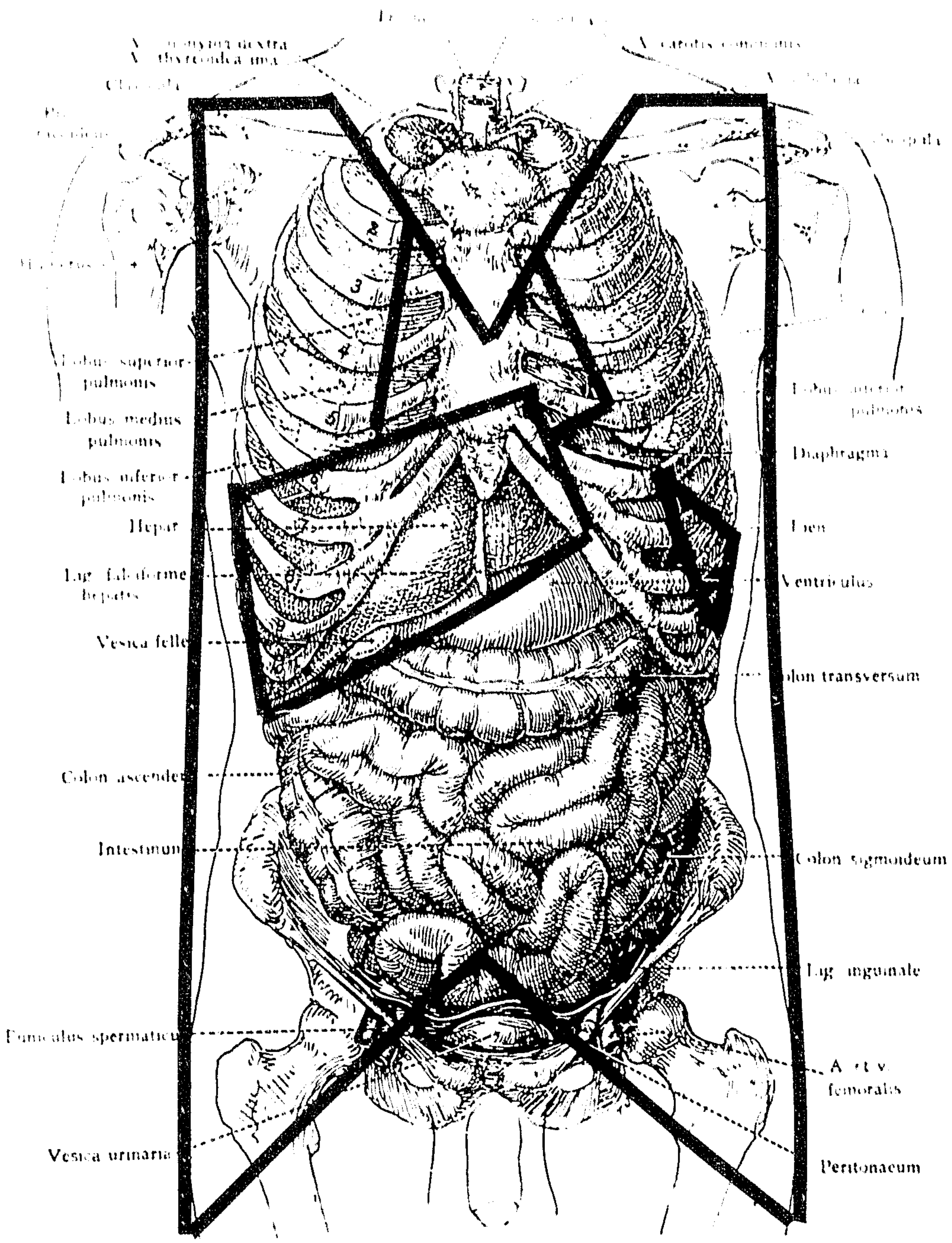


Figure 16. Frontal View with Jacket, Indicating Vulnerable Areas

[The liver (11.9%), heart (5.1%), and spleen (0.8%) account for 17.8% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

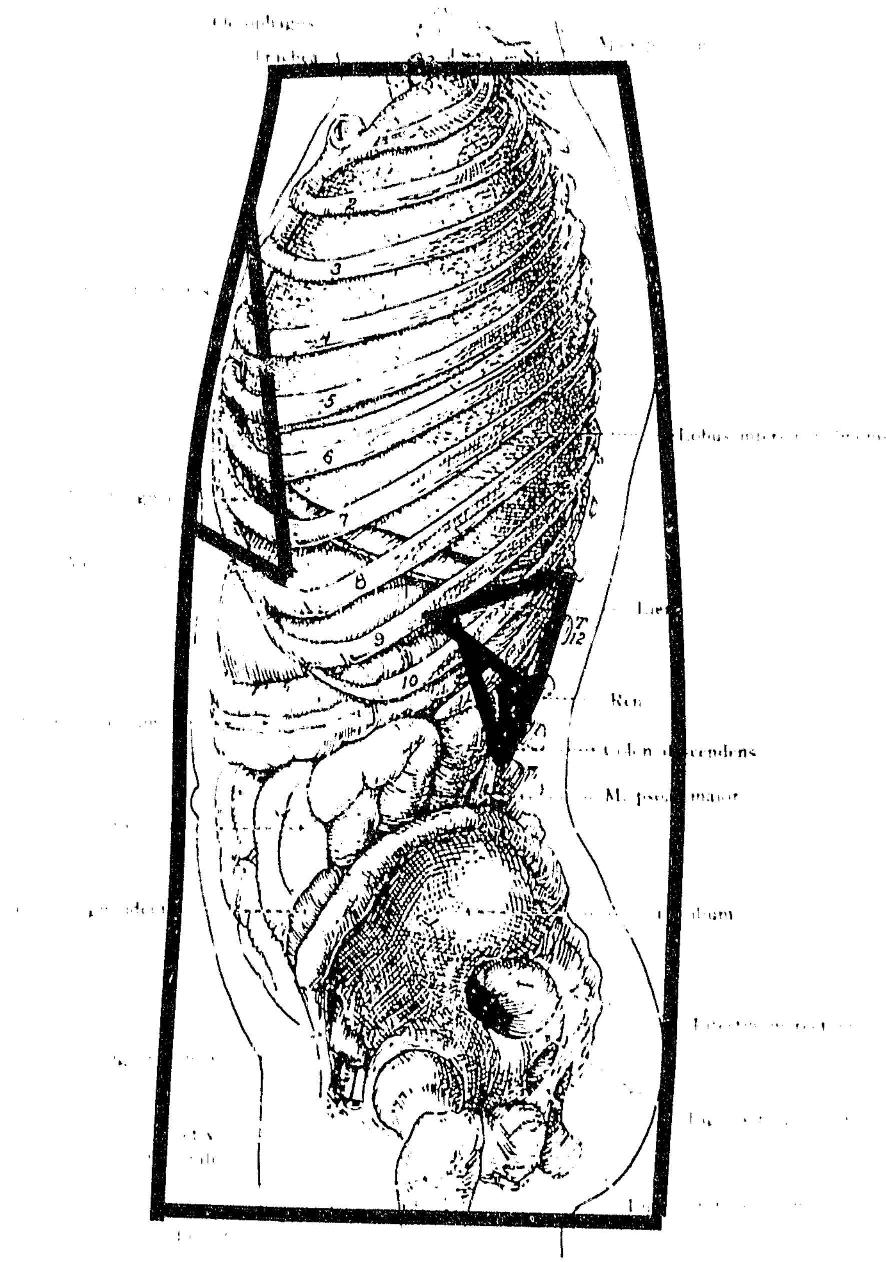


Figure 17. Left Flank View with Jacket, Indicating Vulnerable Areas

[The heart (3.2%), spleen (1.5%), and kidney (0.4%) account for 5.1% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 27th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

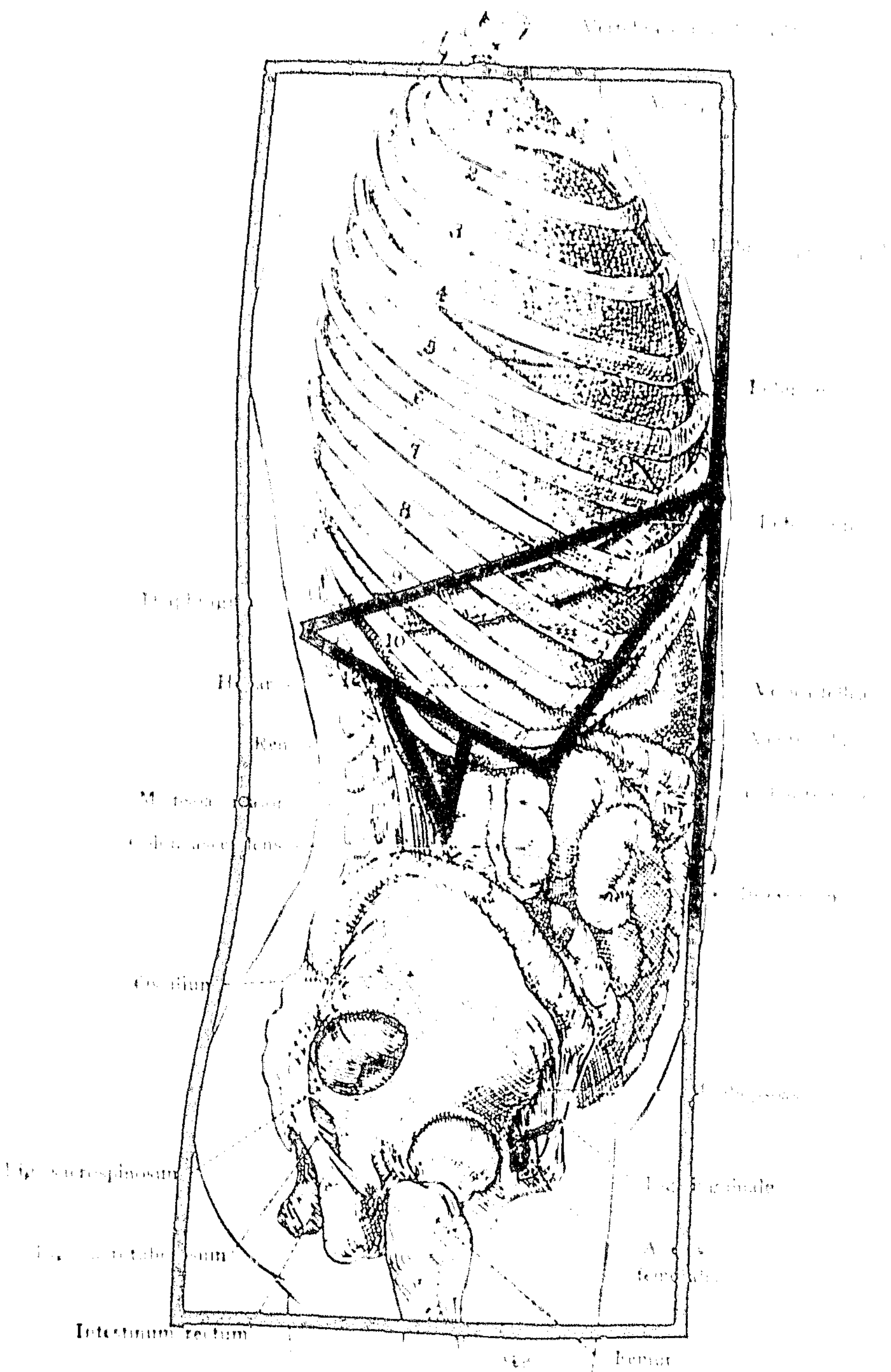


Figure 18. Right Flank View with Jacket, Indicating Vulnerable Areas

[The liver (8.7%) and kidney (0.7%) account for 9.4% of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 2[illegible]th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

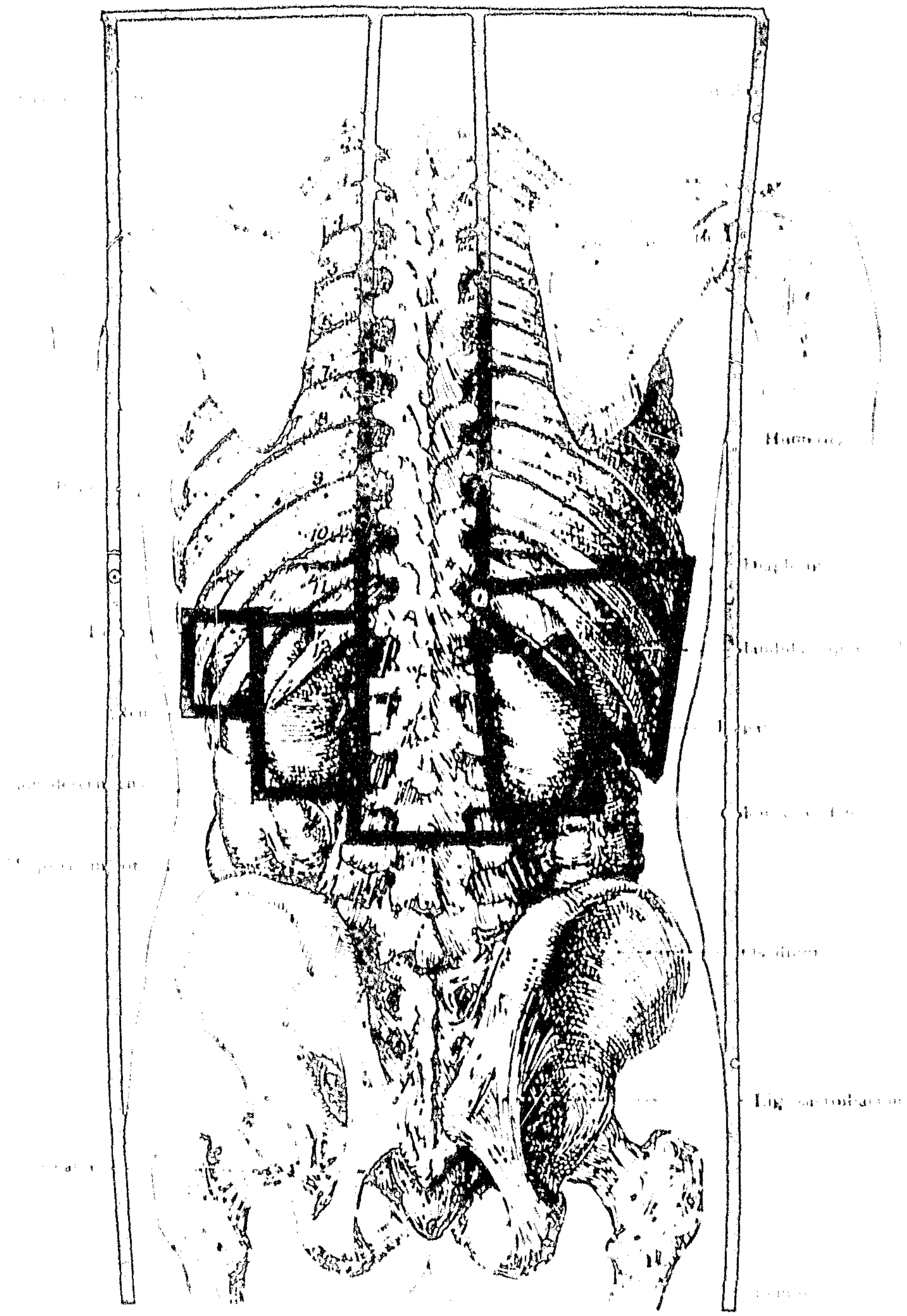


Figure 19. Back View with Jacket, Indicating Vulnerable Areas

[The spleen ([illegible]), kidneys ([illegible]), pancreas ([illegible]), and liver ([illegible]) account for [illegible] of the area covered by the garment. Adapted from Anatomy of the Human Body by Henry Gray. 2[illegible]th Ed. Lea & Febiger, Philadelphia, Pennsylvania.]

1. The area of each of the vulnerable organs was determined for the human target. Thus, for example, on a frontal view the heart accounts for 5.1%, the liver 11.9%, and the spleen 0.8% (table 7). The remaining organs occupy 82.2%. The organs considered to be vulnerable are those organs that revealed damage when the garment was used to protect the goat. The damage would necessitate either observation in an intensive care unit or surgery. The lung, therefore, is not considered vulnerable since there was minimal damage in the 14 goat thoracic impacts.

2. Two mortality rates were then assigned to each area, assuming a garment is *not* worn. One rate may be considered an optimistic evaluation (O), and the other, a pessimistic evaluation (P). These figures are based on data ranges in various surgical series. The "truth" is probably somewhere between these two ranges. With regard to the frontal view, a random liver wound would be associated with a 15% to 60% mortality.

3. The total probability of mortality was calculated by multiplying the mortality times the area fraction of each organ and adding all these probabilities. Thus, in a frontal random shot with a .38 caliber bullet the pessimistic probability of mortality is 0.051 + 0.071 + 0.002 + 0.164 = 0.289 or 28.9%; the optimistic probability is 10.1%.

4. The projected areas of each view are approximately equal. The probabilities for each of the four views were then added and divided by four to derive a mean probability which ranges from 6.9% to 25.4% (table 8). In this step one assumes that each view is hit with equal frequency without armor. From preliminary field data another hit distribution has been suggested. If we assume that a man is hit 60% of the time in the front, 15% in each side, and 10% in the back, how are our final probabilities altered? Calculations reveal an overall change of 2% lower mortality. Regardless of the hit distribution, the mortality is between 7% to 25%.

5. The mortality rates associated with the lesions as a result of blunt trauma beneath the vest were then assigned to the various areas. According to the experimental data, the lungs and non-dilated GI tract are not vulnerable and, therefore, have an associated mortality of zero if impacted while the garment is worn. The liver and spleen injury should carry a mortality of less than 5%. A 10% mortality rate was assigned to the heart.[19] It is possible that this is too high, so further testing is necessary. The spinal injury assessment has been managed by assuming that in one case (optimistic evaluation), no spinal impact would result in death. In the other case, every spinal hit would result in death. Again we believe the "truth" is somewhere between the two estimates. The kidney impact may produce a small hematoma requiring hospital observation, but it is associated with a negligible mortality.

6. Analysis using the mortality rates when armor is worn reveal a range between 1% to 5% (table 9). This represents the mortality associated with a .38 caliber bullet impacting the 7-ply Kevlar.

B. Method to Determine Probability of Surgery with and without Body Armor.

1. In this study we have again considered two alternatives. In the pessimistic case every .38 caliber bullet striking an unarmored human would result in surgery. A more optimistic case is where a penetration to any lung area is associated with a 0.2 probability of surgery (instead of 1.0). The remaining areas would still be associated with surgery on every occasion. In this optimistic case the probability of surgery would be 81.4% (table 10).

2. The probability of surgery if a human is protected by Kevlar is much less. Surgery would be required if the liver or spleen were impacted under the garment. The only other area that might require surgery is the spine. If we consider that surgery is always necessary if the spine is hit (pessimistic case), the total probability for surgery given a random hit anywhere on the garment is 10%. If, however, surgery is not considered when the spine is hit (optimistic case), the total probability for surgery is 7% (table 11).

Table 7. Probabilities of Mortality from a .38 Caliber Bullet without Body Armor for Frontal, Side, and Back Views

(Note that next to each organ "P" represents the pessimistic case and "O", the optimistic case.)

No armor		Mortality rate X	Area fraction of organ	Probability
I. Frontal view				
Heart	P	1.0	0.051	0.051
	O	0.9	0.051	0.046
Liver	P	0.60	0.119	0.071
	O	0.15	0.119	0.019
Spleen	P	0.30	0.008	0.002
	O	0.15	0.008	0.001
Other	P	0.20	0.822	0.164
	O	0.05	0.822	0.041
Total	P			0.289
	O			0.101
II. Left side				
Heart	P	1.0	0.033	0.033
	O	0.9	0.033	0.029
Spleen	P	0.3	0.015	0.005
	O	0.15	0.015	0.002
Kidney	P	0.10	0.004	0.000
	O	0.05	0.004	0.000
Other	P	0.2	0.948	0.189
	O	0.05	0.948	0.041
Total	P			0.227
	O			0.072
III. Right side				
Liver	P	0.60	0.087	0.052
	O	0.15	0.087	0.013
Kidney	P	0.10	0.007	0.001
	O	0.05	0.007	0.000
Other	P	0.20	0.906	0.181
	O	0.05	0.906	0.045
Total	P			0.234
	O			0.058
IV. Back view				
Spleen	P	0.3	0.011	0.003
	O	0.15	0.011	0.002
Kidney	P	0.10	0.047	0.005
	O	0.05	0.047	0.002
Spine	P	1.0	0.135	0.135
	O	0	0.135	0
Liver	P	0.6	0.032	0.019
	O	0.15	0.032	0.005
Other	P	0.2	0.775	0.154
	O	0.05	0.775	0.039
Total	P			0.316
	O			0.048

Table 8. Probability of Mortality If Hit with a .38 Caliber Bullet and not Wearing Body Armor

View	Probability of mortality optimistic case	Probability of mortality pessimistic case
Frontal	0.101	0.289
Left	0.072	0.227
Right	0.058	0.234
Back	0.048	0.316
Mean probability	0.069	0.254

Table 9. Comparison Between Probabilities of Mortality with and without 7-Ply Kevlar If Hit with a .38 Caliber Bullet

View	7-Ply Kevlar	No armor
Front	0.02	0.101 - 0.289
Left	0.01	0.72 - 0.227
Right	0.01	0.058 - 0.234
Back	0.01 - 0.15	0.048 - 0.316
Mean	0.01 - 0.05	0.069 - 0.254

Table 10. Probability of Surgery without Body Armor in Optimistic Case is 81.5% and in Pessimistic Case 100%

View	No armor	Area fraction of organ	Probability of surgery	P
Front	Lung	0.163	0.2	0.033
	Other	0.837	1.0	0.837
	Total			0.870
Left	Lung	0.28	0.2	0.056
	Other	0.72	1	0.72
	Total			0.776
Right	Lung	0.28	0.2	0.056
	Other	0.72	1	0.720
	Total			0.776
Back	Lung	0.194	0.2	0.039
	Other	0.806	1	0.806
	Total			0.835
Average				81.4%

Table 11. Probabilities of Surgery with and without Body Armor (Optimistic Case)

View	7-Ply Kevlar	No armor
Front	0.127	0.870
Left	0.015	0.776
Right	0.086	0.776
Back	0.043 - 0.178	0.835
Mean	0.068 - 0.101	0.814

In summary, *without the garment the mortality after a random hit with a .38 caliber bullet is between 6.9% to 25.4%. If the garment is worn, the mortality is decreased to 1% to 5%. The chance of surgery without armor is 81.5% to 100% and with armor it is 7% to 10%.*

VI. .22 CALIBER BULLET THREAT.

The .22 caliber bullet fired at a velocity of 1000 fps was another missile tested against the 7-ply Kevlar garment. The original batch of Kevlar was backed by gelatin and tested ballistically. Initial studies revealed that the .22 caliber bullet at the stated velocity could be stopped by 7-ply Kevlar. However, a different batch of Kevlar was tested against nine goats (22 shots), and about 50% of the time there was penetration of the material by the .22 caliber bullet at 1000 fps. Photomicroscopy revealed a less dense weave in the second batch. It should be noted that there were two goats with chest impacts and one other goat with multiple abdominal impacts. In the cases where the .22 caliber bullet did not penetrate the material, slight or no observable organ damage occurred. If the .22 caliber bullet is stopped by the material there appears to be little risk of internal damage in the chest or abdomen. The question that then arises is: Can a better controlled, tighter weave, as in the first batch, be guaranteed?

VII. GARMENT AGING.

All the Kevlar tested was "new." Material that has been "used," that is, undergone some degree of rapid aging, will be tested in the future. The techniques of rapid aging must be agreed upon. Certainly one could not state without testing that a garment fashioned from used Kevlar protects as well as a new one.

VIII. CONCLUSION.

As a final note in this report, we would like to again emphasize the exact scope of our investigation to date. That is, we have had success with the unaged 7-ply Kevlar vest against the threat of the .22 caliber bullet traveling at a velocity of 1000 fps and the .38 caliber traveling at 800 fps. No inference can or should be drawn from these tested threats to other partially or totally untested threats such as the .45 caliber bullet, 9-mm bullet, shotgun, or higher velocity weapons. Thus, from the blunt trauma aspect of our investigations, only the damage produced by the .38 caliber and the .22 caliber bullets beneath the 7-ply, unaged Kevlar vest has been evaluated.

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