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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: ARCSL-TR-77057
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): THE MEDICAL ASSESSMENT OF A NEW SOFT BODY ARMOR
5. TYPE OF REPORT & PERIOD COVERED: Technical Rep[redacted]t Dec[redacted]75–Dec[redacted]76
6. PERFORMING ORG. REPORT NUMBER:

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8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
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10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
LEAA-J-IAA-005-4
US Department of Justice
11. CONTROLLING OFFICE NAME AND ADDRESS:
Director, Chemical Systems Laboratory
Attn: DRDAR-CLJ-R
Aberdeen Proving Ground, Maryland 21010
12. REPORT DATE: Jan[redacted]78
13. NUMBER OF PAGES: 20
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: NA
16. DISTRIBUTION STATEMENT (of this Report):
Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
SBIE AD-E410 002
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Blunt trauma
Medical study correlation
Design and fabrication
Threat levels
Myocardial contusions
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This task has been a 12-month project to evaluate lightweight protective garments being used by law enforcement officers to defeat most handgun threats.

This document defines the general tasks required on the part of the US Army (Chemical Systems Laboratory, USA ARRADCOM, Aberdeen Proving Ground, Maryland, and USA Natick Research and Development Command).

PREFACE

The joint study described was originally tasked (January 1973) to the US Army Land Warfare Laboratory (LWL), Aberdeen Proving Ground, Maryland, by the National Institute of Law Enforcement and Criminal Justice (NILECJ), Law Enforcement Assistance Administration (LEAA), US Department of Justice. Shortly thereafter LWL was abolished and overall responsibility of the program was transferred to the Biophysics Division, Chemical Laboratory, Edgewood Arsenal,* Aberdeen Proving Ground, Maryland. The LWL Program Manager, Mr. Nicholas Montanarelli, provided overall coordination of the project and transferred with the program to Chemical Laboratory. Mr. Clarence E. Hawkins is Project Officer of the Lightweight Body Armor Program for the Biophysics Division. Design, fabrication, and testing of different types of garments were provided under the direction of Mr. Edward R. Barron, Chief of Body Armor Section, Natick Research and Development Command, Natick, Massachusetts. Materials for testing and specifications were furnished by Natick Research and Development Command under the direction of Dr. Roy C. Laible, Chief of Fiber and Technology Branch.

The Aerospace Corporation, El Segundo, California, assisted the Army laboratories by providing operational requirements, limited amounts of ballistic, environmental, and laboratory testing, as well as technical support in the area of material phenomena. Further prototype testing will be undertaken by Aerospace Corporation and directed by Mr. Louis G. King, Aerospace Corporation's Project Manager.

Aerospace Corporation has been programmed to furnish 4,000 protective soft body armor garments for full-scale field testing through to FY 1976. Natick Research and Development Command will assist in providing procurement specifications for material weaving and fabrication of the garments. Edgewood Arsenal shall provide a medical team to support the field testing of the garments.

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.

* Now Biophysics Branch, Research Division, Chemical Systems Laboratory.

Acknowledgments

We wish to acknowledge the assistance of the Biophysics personnel who participated and have our highest esteem for their outstanding performance which has resulted in the successful conclusion of this program. These personnel are: William J. Sacco, Ph.D., Michael A. Weinstein, M.D., and Michael A. Goldfarb, M.D.

The authors wish to acknowledge the overall support and administrative guidance received from personnel of the Law Enforcement Assistance Administration, US Department of Justice, Washington, DC, particularly Joseph T. Kochanski and George Schollenburger.

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I. INTRODUCTION.

Since the 1960's, an increasing number of police officers have been assaulted by firearms. Attempts against the lives of public officials have also marred this period, including the assassinations of a president, a presidential candidate, and a prominent civil rights leader.

The handgun represents the most commonly used weapon in assaults against police personnel. F.B.I. statistics for the 10-year period from 1964 through 1973 showed:[1]

1. Seventy-four percent of police fatalities involved handguns.

2. The "common" handguns and "Saturday night specials" (.38, .380, .32, .25, .22 caliber) represented 81% of the handguns used in the fatal police assaults.

In 1973, a multi-institutional program, including the US Army Land Warfare Laboratory (LWL) and the Law Enforcement Assistance Administration (LEAA), was initiated to develop a new lightweight, inconspicuous, soft body armor. Armors then available were generally of the heavy, bulky military variety.

After ballistic tests using various materials, a lightweight synthetic fiber, Kevlar-29 (Du Pont), was selected for use in body armor fabrication. Seven layers of this high tensile strength material consistently prevented penetration by a .38-caliber threat at 800 ft/sec and a .22-caliber threat at 1000 ft/sec.[2]

In addition to ballistic studies, biological and mathematical methodologies assessing the protective qualities of a seven-layer Kevlar soft body armor were developed at the US Army's Biophysics Division, Chemical Laboratory (Edgewood Arsenal) (now Biophysics Branch, Research Division, Chemical Systems Laboratory).

II. MATERIALS AND METHODS.

Animal experiments were conducted in accordance with the Guide for Laboratory Animal Facilities and Care. These studies were carried out on anesthetized, intubated goats weighing approximately 40 kilograms. Goats protected with Kevlar armor were assaulted with .38-caliber, 158-grain lead threats at velocities of approximately 800 ft/sec. Shots were targeted over various parts of the body to assess the blunt trauma produced behind armor that defeats a missile, i.e., prevents penetration. Threats to the lungs were targeted over the lateral chest in the sixth and seventh intercostal spaces. Cardiac threats were targeted on the "cardiac window" during end expiration. Intestinal threats were targeted on the midanterior abdominal wall; whereas hepatic and splenic threats were directed, respectively, to the right and left lower lateral thoracic cage in the eleventh intercostal space. In addition, strikes over the protected spinal column were carried out.

In each series of shots, various parameters were monitored depending upon the organ under study. In the cardiac shots, ECG's, cardiac outputs, arterial blood gases, and enzymes were monitored. In the pulmonary shots, arterial blood gases were measured. Neurologic assessments were made following the spinal shots. In all studies, the systemic blood pressure and the parameters peculiar to each study were measured before and after assault, 1 hour after assault, and prior to sacrifice which was carried out at 24 hours. In the spinal shots, sacrifice occurred at 48 hours. In all cases, immediate necropsy was performed.

III. RESULTS.

Typical skin wounds, behind the unpenetrated armor, consisted of an area of superficial laceration about 2 to 4 cm in diameter surrounded by an ecchymotic and erythematous area (figure 1). Lacerations occasionally extended into the underlying thoracic and abdominal wall muscles, but penetration into these cavities was not seen.[3]

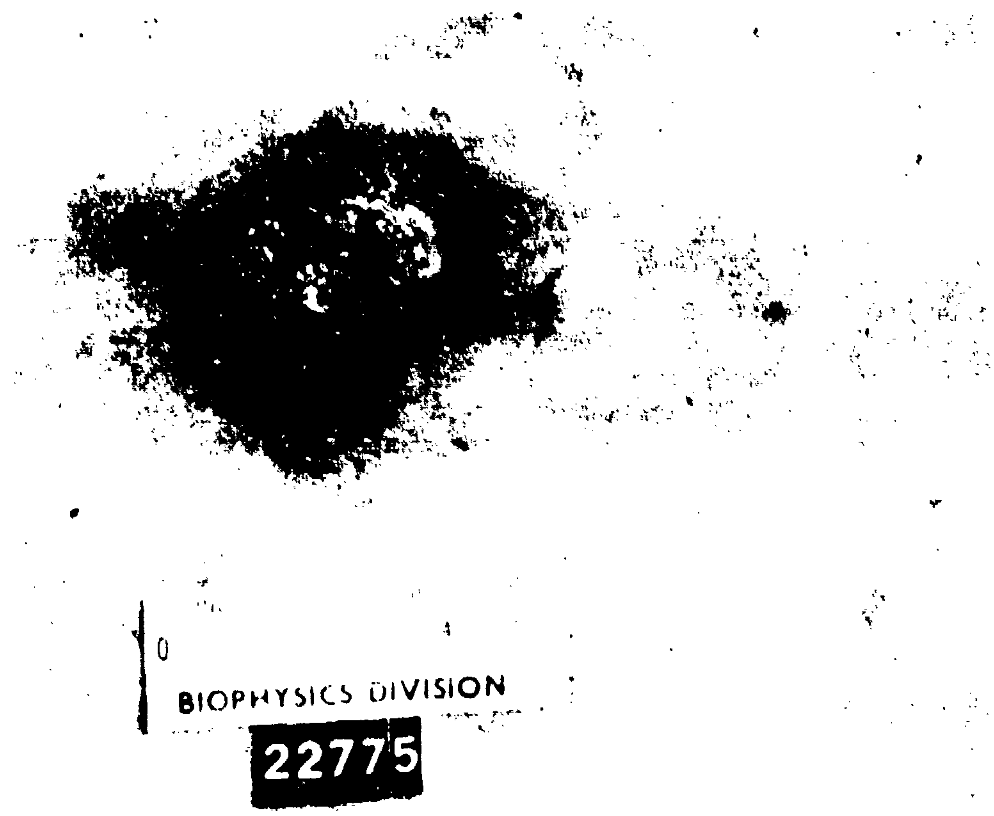

Figure 1. Typical Skin Lesion Behind Unpenetrated Armor in Experimental Animal

Necropsy demonstrated the following injuries:

1. Four of eight assaults over dilated bowel resulted in perforations; whereas, in 13 assaults over nondilated bowel, no perforations occurred. Minor serosal and omental contusions were seen in this second group.

2. Assaults over the liver produced liver contusions or singular small fractures in 14 of 18 cases. Two associated, nondisplaced rib fractures were also noted. The amount of injured tissue averaged less than 50 cc. No more than 100 cc of blood was found in the abdominal cavity in

any case. Although many of these injuries would have required laparotomy in humans, it was estimated that a marked reduction in morbidity and mortality would have been produced by armor protection, since the singular injuries were small and not associated with significant hemorrhage.

3. In 25 thoracic shots, small pulmonary contusions (20 cc or less) were seen in 20 cases. The largest lesion measured 96 cc of excised tissue. In addition, in six cases, singular nondisplaced rib fractures were seen. In all cases, no significant changes in arterial oxygenation or systemic blood pressure were encountered.

4. In two of seven initial cardiac tests, a stiff, indwelling, left-ventricular end-diastolic catheter was felt to be the iatrogenic source of aortic root injuries seen. In 15 subsequent tests (after removal of the catheter), one significant injury was noted, disruption of two aortic valves. The animal with this injury demonstrated moderate hypoxemia prior to sacrifice. One animal without evidence of myocardial contusion demonstrated transient premature ventricular contractions prior to sacrifice. In all other cases, no conduction defects or arrhythmias were seen.

5. The spleen proved to be an elusive target. Three attempts were made to hit this small organ which has a variable orientation in the goat. In one case, a 2-cm contusion was demonstrated on the inferior edge of the spleen. In the two other cases, no damage was seen in one; and, in the other, there was poor targeting.

Since the spleen is a friable organ, it is expected that a hit over this organ in the human could result in at least a contusion or subcapsular hematoma. Both of these injuries could eventually lead to laparotomy.

6. Seven of seven shots over the spinal column resulted in isolated spinous or transverse process fractures. In four shots demonstrating shots producing transverse process fractures, transient hind leg paresis was evident. In two cases, the weakness disappeared in about 1 hour; and, in the third, the weakness resolved within 24 hours. In none of the spinal shots was morphologic or histologic evidence of spinal cord injury demonstrated.

Because of the larger size of the spinous processes in goats compared to man, it is estimated that the goat is provided with better protection against blunt trauma injury. Hence, a shot over the human spinal column could possibly result in weakness or even contusion of the spinal column. To more accurately predict the results of a human spinal column impact, another species with similar spinal anatomy could be used in ballistic tests.

The innocuous appearance of typical skin lesions, occurring behind the armor, did not correlate with the presence or absence of internal injury.

IV. CLINICAL CORRELATION.

In addition to the above studies, a mathematical methodology was developed relating surface areas of the body protected by the armor with the probability of injury to underlying organs, with and without protection. The probable necessity of surgical treatment was also calculated.

Results indicate:

Survival probability	Percent
With armor	95-99
Without armor	75-93
Surgery probability	**Percent**
With armor	7-10
Without armor	82-100

Since these calculations were based on pessimistic estimates of pathology, the protective qualities of the Kevlar armor are thought to be better than indicated.

Organs considered to be vulnerable in man were those organs which demonstrated injury in the goat ballistic studies. According to the experimental data, these included the heart, liver, spleen, and spinal cord. A kidney impact may produce a small contusion requiring hospital observation, with negligible mortality. The lungs and nondilated gastrointestinal tract were not considered vulnerable when protected by the Kevlar armor.

LEAA began a field evaluation of the seven-layer Kevlar armor in December of 1975. In 15 cities, selected on the basis of police assault rates and environmental factors, law enforcement personnel were issued Kevlar soft body armors (figure 2).

To date, a medical and ballistic assessment team from the Edgewood Arsenal has investigated five assault incidents.

A. Case I.

A 33-year-old policeman was assaulted with a handgun upon interrupting a burglary in progress. Two .38-caliber, 158-grain lead bullets struck his chest without penetrating his seven-layer LEAA garment. The assaults occurred at an estimated range of less than 4 feet. After impact, the officer was able to pursue his assailant. He experienced no loss of consciousness or dyspnea. Behind the armor, two wounds were noted: a 3- by 4-cm lesion located on the right chest slightly lateral to the mid-clavicular line at the level of the second intercostal space and a 6- by 4-cm lesion noted over the left sternal border at the level of the fourth intercostal space. Both wounds showed areas of contusion, abrasion, and superficial central laceration, similar to the lesions seen in the animal tests (figure 3). Soon after hospital admission, an orthopedic procedure for an associated left-hand wound was performed under regional anesthesia. No cardiac irregularities were noted during surgery or in the subsequent 24-hour period of cardiac monitoring. An initial arterial blood gas sample and subsequent serial ECG's, chest X-rays, and isoenzyme determinations revealed no evidence of cardiac or pulmonary injury. The patient was discharged on the third hospital day.

Figure 2. Seven-Layer Kevlar Soft Body Armor Prototype

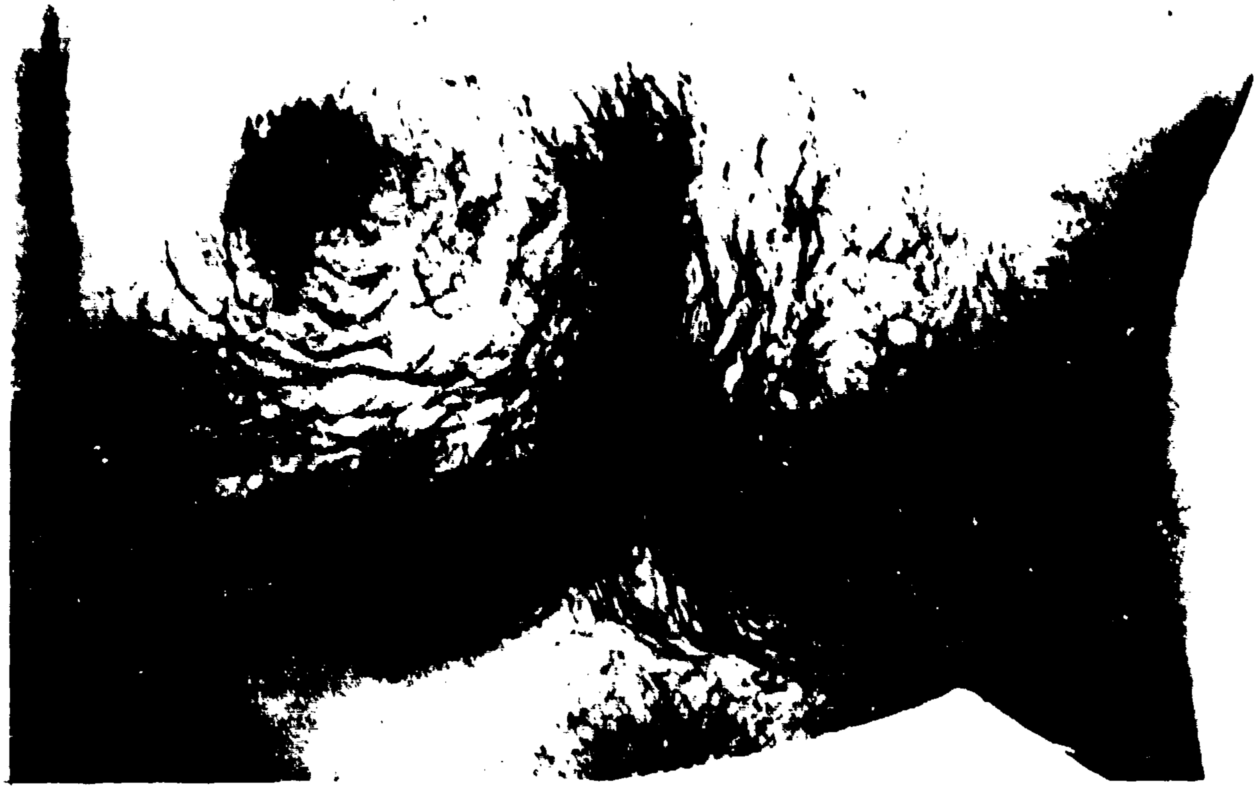

Figure 3. Skin Lesions Noted in Emergency Room Soon After Assault in Case I

(Courtesy of P. E. Besant-Matthews, M.D.)

B. Case II.

A 28-year-old policeman was assaulted with a handgun while investigating a burglary. A .22-caliber, 40-grain missile delivered at a range of about 6 feet did not penetrate the officer's seven-layer Kevlar armor. (Subsequent chronography of the weapon revealed a muzzle velocity of 1136 ft/sec.) After the impact over the left chest, the officer, noting only slight wound discomfort, pursued his assailant. Hospitalization for observation of possible intrathoracic injury followed. A 2- by 3-cm wound exhibiting abrasion and central laceration was noted behind the armor 1 inch lateral to the left nipple (figure 4). The patient was placed in a cardiac care unit for 24 hours of monitoring. No cardiac ectopy was seen. Vital signs remained stable. Serial ECG's, chest X-rays, and an isoenzyme determination were within normal limits. The patient was discharged 48 hours after the ballistic assault.

Figure 4. Skin Lesion Noted in Emergency Room Soon After Assault in Case II

(Courtesy of D. K. Wiecking, M.D.)

C. Case III.

A 46-year-old policeman was assaulted while searching for a gunman in a darkened restaurant. The officer's armor, composed of 14 layers of Kevlar and two layers of ballistic nylon, with front and back panels, lacked lateral torso protection. The officer was struck twice at a range of 4 to 5 feet. The first missile consisted of pellets from a .38 caliber "shot shell." A few of these pellets struck the left arm and head causing minor tissue damage. A second .38-caliber bullet tunneled subcutaneously through the lateral right thorax and exited striking the edge of the back panel. Post-assault dyspnea did not occur, and the patient was unaware of his chest wound until hospitalized. Vital signs on admission were stable and remained stable. A groovelike 1- by 4-cm entrance wound was noted at the level of the fourth rib on the right lateral chest wall. The groove pointed to a 1-cm round exit wound posterior at the level of the tenth rib. Serial chest X-rays were within normal limits, and the patient was discharged on the second hospital day.

In addition to the three cases presented in the LEAA field evaluation program, two additional incidents of assault against commercial soft body armors were investigated.

D. Case IV.

A 30-year-old policeman was shot over the lower sternal area while making a traffic investigation. The .38-caliber missile delivered at a close range became embedded in the officer's vest after penetrating two of its eighteen layers of ballistic nylon. A second missile struck the unprotected left shoulder and lodged in the musculature of the right posterior neck. After impact, the officer was able to take protective action. Hospitalization followed the assault. A 4- to 5-cm circular contusion with superficial laceration was noted over the right xiphoid margin. No radiographic or electrocardiographic evidence of intrathoracic trauma was noted. The patient was discharged on the third hospital day.

E. Case V.

A 26-year-old policeman was shot with a handgun over the right thoracic cage, while wrestling with a criminal suspect. His 15-layer Kevlar armor was not penetrated. After the point blank assault, the officer continued the struggle and arrested the assailant. The missile, a 125-grain, jacketed hollow-point .38-caliber bullet, produced a 5- by 5-cm area of contusion and abrasion on the right lateral chest wall over the sixth costal-chondral junction (figure 5). Upon hospitalization, physical examination and serial radiographs revealed no evidence of intrathoracic injury. Discharge occurred on the second hospital day.

Figure 5. Healing Skin Wound in Case V, Five Days After Assault

V. DISCUSSION.

In the defeat of a bullet by Kevlar armor, kinetic energy must be dissipated. Energy is expended in deformation of the missile, armor, and underlying body wall, transferred to the body, and lost as heat. On impact, the armor is pushed against the body wall, forcing both inward. Studies were carried out at the Edgewood Arsenal Biophysics Division to define the configuration of the deformed Kevlar armor. This deformation, defined as the "backface signature" of the armor, was studied using high-speed photography. Motion pictures of backlighted 20% gelatin blocks documented the deformation of the armor into the gelatin when impacted by a missile. Analysis revealed the depth and shape of the deformation, including the time required to reach maximal depth of penetration. These studies demonstrated a symmetric conical deformation of the armor into the gelatin when struck at 0° obliquity.

With seven layers of Kevlar material, in 17 shots using .38-caliber, 158-grain bullets with an average velocity of 251 m/sec (822 ft/sec) and a kinetic energy of 32 joules (237 ft-lb), a maximal "backface signature" deformation was reached in an average of 1.7 milliseconds (S.D. ± 0.002).[4]

The deformed cone of armor, smashing into the body wall, over a discrete area in a short interval, describes a unique mechanism capable of producing trauma. This rapid jolting force focused on a small area, much like an "impulse", contrasts greatly with the usually encountered mechanisms producing blunt trauma injury; i.e., those delivered by large objects, over large areas, with relatively prolonged periods of force application.

A host of methodologies have been described to produce experimental blunt trauma to the torso. Some methods have centered on explaining the pathophysiology of blast injury;[5,6] whereas others have addressed themselves to injuries produced when blunt objects strike the body. Much of this latter work has been directed at characterizing trauma seen in vehicular accidents, such as the steering column injury. These techniques include: striking the exposed heart *in vivo*,[7] striking the perfused liver,[8] strikes to the precordial area using a captive bolt gun apparatus,[9,10] ramming the abdomen of a stationary animal with a blunt object,[8] and propelling an animal into a blunt object.[11]

Thus, previous methods used to produce blunt trauma generally employed larger objects impacting larger surfaces. In addition, the application of force was generally over a long period of time relative to the 2-millisecond "impulse" in the ballistic studies.

Much of the blunt trauma experience in the clinical literature is not comparable to that seen behind a pliable body armor. Series presenting blunt trauma injuries of the heart[12,13] aorta,[14] and intestines[15] are heavily weighted by vehicular trauma. However, clinical and research experience in blunt trauma is not to be dismissed when considering blunt injury relative to soft body armor. This vast experience has documented the insidious nature of blunt trauma injury.

Although the assessment of the protective qualities of a soft body armor prototype continues, the results of the cases presented in this report are most encouraging.

In cases I, II, and IV, a projectile directed at or near the heart and great vessels, at close range, was easily defeated by the armor. Had penetration occurred, a serious chest wound necessitating emergency surgery would have resulted. A fatal outcome could have been postulated in each case. However, surgery was avoided (except for an associated hand wound) and hospitalization was short. In case V, the armor prevented penetration by a missile directed at an area occupied by both the lung and liver.

The injuries sustained by the policeman in case III, although fortunately not serious, convince the authors that a torso-encircling armor with lateral protection is the best protective design.

VI. SUMMARY.

The development of a new lightweight soft body armor appears to lower the morbidity and mortality from certain ballistic threats. "Impulse"-type blunt injuries have been produced in laboratory animals. The severity of underlying injury (if any) did not correlate with the seemingly innocent skin lesion seen behind the armor. Therefore, in the case of impact on a soft body armor, it is recommended that:

1. All victims of assault should be hospitalized for observation in spite of an apparent state of good health and a minimal skin lesion.

2. Strikes to the chest should be monitored with serial chest X-rays.

3. Strikes to the precordial region require cardiac monitoring and serial ECG's and enzyme determinations. and

4. Strikes to the abdomen require frequent examination for signs of peritoneal irritation. Impacts over the liver should be viewed with great suspicion of underlying hepatic injury.

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