

# A New Nonpenetrating Ballistic Injury

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A new, nonpenetrating ballistic injury mechanism involving individuals protected by soft body armor is described. Experimental studies using laboratory animals have demonstrated that despite stopping missile penetration, the heart, liver, spleen, and spinal cord are vulnerable to injury. The rapid jolting force of an impacting bullet is contrasted with the usually encountered mechanisms producing blunt trauma injury. The experimental methodology used to assess a 20% increase in survival probability and an 80% decrease in the need for surgical intervention with a new soft body armor is reviewed. Five cases of ballistic assaults on law enforcement personnel protected by soft body armor are presented. Four emphasize the potentially lifesaving qualities of the armor, while the fifth indicates the need for torso encircling design. Hospitalization should follow all assaults, regardless of the innocuous appearance of the skin lesion and the apparent well being on the assaulted individual. Therapeutic guidelines for patient management are suggested.

SINCE THE 1960's, an increasing number of police officers have been assaulted with 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 ten year period from 1964 through 1973 showed that 74% of police fatalities involved handguns. The "common" handguns and "Saturday night specials" (.38, .380, .32, .25, .22 caliber) represented 81% of the handguns used in the fatal police assaults.<sup>18</sup>

In 1973, a multi-institutional program, the US Army Land Warfare Laboratory (LWL) and the Law Enforcement Assistance Administration (LEAA), was

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initiated to develop a new lightweight, inconspicuous, soft body armor. Armors then available were generally of the heavy, bulky military type.

After ballistic tests using various materials, a lightweight synthetic fiber, Kevlar-29® (Dupont), was selected for use in body armor fabrication. Seven layers of this high tensile strength material consistently prevented penetration by a .38 caliber missile at 800 ft/sec and a .22 caliber missile at 1000 ft/sec (Fig. 1).<sup>14</sup>

In addition to ballistic studies, biologic and mathematical methodologies assessing the protective qualities of a seven layer Kevlar soft body armor were developed at the US Army's Biophysics Division (Edgewood Arsenal).

## Experimental Group Materials and Methods

Animal experiments were conducted in accordance with the *Guide for Laboratory Animal Facilities and Care*.<sup>†</sup> These studies were carried out on anesthetized, intubated goats weighing approximately 40 kg. Goats protected with Kevlar armor were assaulted with .38 caliber 158 grain lead bullets 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 or seventh intercostal spaces. Cardiac threats were targeted on the "cardiac window" during end expiration. Intestinal threats were targeted on the midanterior abdominal wall, while 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.

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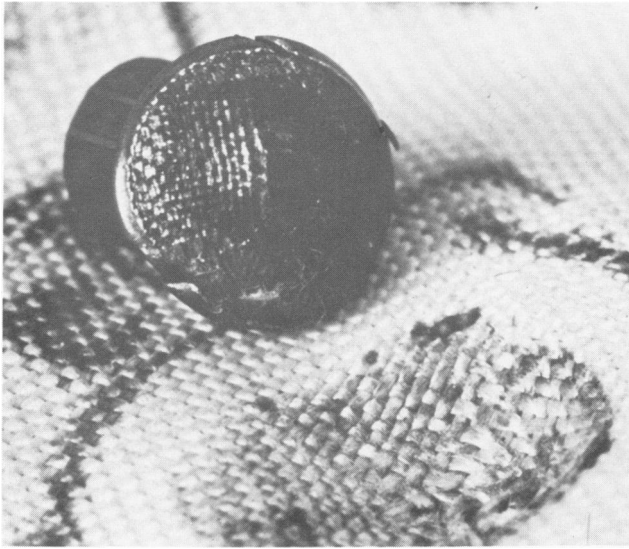


FIG. 1. Deformed .38 caliber bullet following impact at 811 ft/sec on Kevlar material. Note the weave impression of nonpenetrated material imparted to the missile.

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 pre- and postassault, one 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.

#### Experimental Group Results

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

Necropsy demonstrated the following injuries:

1) Four of eight assaults over dilated bowel resulted in perforations, while in eight assaults over nondilated bowel no perforations occurred. Minor serosal and omental contusions were seen in this latter group.<sup>9</sup>

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. This animal demonstrated moderate hypoxemia prior to sacrifice. One animal without evidence of a myocardial contusion demonstrated transient PVC's prior to sacrifice. In all other cases, no conduction defects or arrhythmias were seen.<sup>17</sup>

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.<sup>9</sup>

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 spinous process fractures, no neurologic deficits were noted. In three shots producing transverse process fractures, transient hind leg paresis was evident. In two cases, the weakness disappeared in about one hour and, in the third, resolved within 24 hours. In none of the spinal shots was morphologic or histologic evidence of spinal cord injury demonstrated.<sup>9</sup>

Because of the relatively 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 should 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.

### 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 (Table 1).<sup>9</sup>

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.

The Law Enforcement Assistance Administration (LEAA) began a field evaluation of the 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.

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

### Case Reports

**Case 1.** 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 four feet. After impact, the officer was able to pursue his assailant. He experienced no loss of consciousness or dyspnea.

TABLE 1. *Probability of Survival and Necessity of Surgery with and without Armor*

Probability	Per Cent
Survival	
with armor	95-99
without armor	75-93
Surgery	
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.



FIG. 2. Skin lesions noted in emergency room immediately after assault on Case I (courtesy of P. E. Besant-Matthews, M.D.).

Behind the armor, two wounds were noted: a 3 × 4 cm lesion located on the right chest slightly lateral to the midclavicular line at the level of the second intercostal space, and a 6 × 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 (Fig. 2). 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 subsequent 24 hour period of cardiac monitoring. An initial arterial blood gas 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.

**Case 2.** A 28-year-old policeman was assaulted with a handgun while investigating a burglary. A 40 grain, .22 caliber missile delivered at a range of about six 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, experiencing only slight discomfort, pursued his assailant. Hospitalization for observation of possible intrathoracic injury followed. A 2 × 3 cm wound exhibiting abrasion and central laceration was noted behind the armor one inch lateral to the left nipple (Fig. 3). 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 isoenzyme determinations were within normal limits. The patient was discharged 48 hours after the ballistic assault.

**Case 3.** 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 of ballistic nylon, with front and back panels, lacked lateral torso protection. The officer was struck twice at a range of four to five feet. The first missile consisted of pellets from a .38 caliber "shot shell." A few of these pellets struck the left front panel resulting in no armor penetration or evidence of underlying tissue damage. A second .38 caliber bullet tunneled subcutaneously through the lateral right thorax and exited striking the edge of the back panel. Postassault



FIG. 3. Skin lesion noted in emergency room immediately after assault in Case II. (courtesy of D. K. Wiecking, M.D.).

dyspnea did not occur, and the patient was unaware of his chest wound until hospitalized. Vital signs on admission were stable and remained as such. The patient also sustained pellet wounds of the left arm, shoulder, and face area. These missiles embedded subcutaneously, causing discomfort but no serious injury. Serial chest x-rays were within normal limits, and the patient was discharged on the second hospital day.

### Comment

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.

**Case 4.** 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 4.5 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.

**Case 5.** 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 × 5 cm area of contusion and abrasion on the right lateral chest wall over the sixth costal-chondral junction. Upon hospitalization, physical examination and serial radiographs revealed no evidence of intrathoracic injury. Discharge occurred on the second hospital day.

### 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 158 grain, .38 caliber bullets with an average velocity of 251 m/sec (822 ft/sec), having a kinetic energy of 322 joules (237 ft-lbs), a maximal "backface signature" deformation was reached in an average of 1.7 millisecond (S.D. ± 0.002).<sup>13</sup>

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 has been described to produce experimental blunt trauma to the torso. Some methods have centered on explaining the pathophysiology of blast injury,<sup>2,20</sup> while 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*,<sup>3</sup> striking the perfused liver,<sup>19</sup> strikes to the precordial area,<sup>6,7,11</sup> ramming the abdomen of a stationary animal with a blunt object,<sup>19</sup> and propelling an animal into a blunt object.<sup>8</sup>

Thus, previous methods used to produce blunt trauma generally employed large objects impacting large surfaces. In addition, the application of force was generally over a long period of time relative to the 2 msec "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,<sup>5,10</sup> aorta,<sup>15</sup> lungs,<sup>1</sup> liver,<sup>12,16</sup> and intestines<sup>4</sup> 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 1, 2, and 4, 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 5, 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 3, although fortunately not serious, convinces us that a torso encircling armor with lateral protection is the best protective design.

A new lightweight soft body armor appears to lower the morbidity and mortality from certain ballistic threats. We feel, however, that a new injury mechanism and clinical presentation have been defined. Based on studies using laboratory animals, the severity of underlying injury may not correlate with the seemingly innocent skin lesions. 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. 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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