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The Shielding Capacity of the Standard Military Flak Jacket Against Ballistic Injury to the Kidney

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ABSTRACT: An animal model was designed to evaluate the ability of the standard military flak jacket to protect the kidneys from direct ballistic trauma. Yorkshire swine were anesthetized and their flanks were protected by flak jackets. Ballistic insults ranging from a low-velocity handgun to a high-velocity rifle were evaluated. The results demonstrate that a flak jacket provides adequate protection against low- and mid-velocity projectiles since none of the animals from this group had evidence of internal trauma and because only minor superficial surgical attention would have been required. Survivability in each case was considered to be excellent. The flak jacket failed to provide any protection against several types of high-velocity bullets. These weapons caused severe internal injury to the genitourinary system as well as to other major organ systems. Survival would have been unlikely.

KEYWORDS: pathology and biology, ballistics, wound ballistics, protective clothing

Previous prospective ballistic experimentation has evaluated trauma to the heart and lungs [*1-3*], major vasculature [*4,5*], muscle [*6,7*], and those organs of special interest to the general surgeon [*3,6,8*]. The genitourinary system has been largely overlooked by these studies, and most of our knowledge is based on retrospective information obtained during World War II, the Korean War, and the Vietnam conflict [*9-12*]. The lack of research data makes it extremely difficult for military urologists to make specific recommendations concerning the treatment of ballistic injuries to the genitourinary tract. Experimentation over the past five years has demonstrated differences between low- and high-velocity ballistic trauma to the porcine urinary system both in vivo and in vitro [*13-16*].

As a continuation of these studies, attention has now been focused upon a model which evaluates the ability of a standard military flak jacket (Body Armor, Fragmentation Protec-

The opinions contained herein are those of the authors and are not to be construed as official or as reflecting those of the Departments of the Navy, the Air Force, or Defense. The investigators adhered to the principles described in *Guide for the Care and Use of Laboratory Animals* [*19*]. Received for publication 6 May 1987; accepted for publication 5 June 1987.

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tive Vest) to protect the kidneys against direct ballistic injuries. The flak jacket was introduced for Marine Corps troops during World War II and subsequently adopted by all services. The flak jacket that is currently issued to United States military personnel is made of layered Kevlar®, a tightly woven synthetic material which has an ability to dissipate the energy of an oncoming projectile. Body armor designed to deflect high-velocity rifle missiles must use strike plates made of hardened steel or ceramic material. High-velocity projectiles (greater than 2500 ft/s [762 m/s]) penetrate the plates, are quickly decelerated, and are then captured by a low-velocity mesh in the armor. The standard issue flak jacket does not contain strike plates since it was primarily designed to provide protection against fragmentation wounds caused by low-velocity shell fragments and debris. Nonetheless, there is evidence that it does have some bullet-deflecting ability [*17*].

The flak jacket's efficacy in protecting against direct ballistic injury has never been evaluated using a range of low- and high-velocity missiles. A single technical report describes the effects of low velocity .38 caliber projectiles on anesthetized 40-kg goats protected by samples of body armor consisting of seven-ply 400 denier weight Kevlar [*18*]. Projectiles shot at the abdomen of the animals produced superficial cutaneous lacerations with only minor intestinal and omental contusions, as long as the gastrointestinal tract was not dilated. The goats occasionally developed marked dilation of the rumen while under anesthesia, which then became more susceptible to laceration during bullet impact. Of the animals who exhibited dilation of their gastrointestinal tract, 50% suffered lacerations of the rumen. No other abdominal or retroperitoneal injuries were noted. Thoracic, cardiac, splenic, liver, and spinal cord assaults were also performed, but the investigators did not address the genitourinary system. Their results indicated that the chance of survival following ballistic injury increased from 75 to 95% and that the probable need for surgery decreased from 80 to 100% without flak jackets to 7 to 10% when flak jackets were used [*18*].

The following study was designed to evaluate the flak jacket's efficacy in protecting the kidneys against direct ballistic trauma from a variety of low- and high-velocity projectiles.

Materials and Methods

The study was performed on 100- to 150-lb (45- to 68-kg) Yorkshire swine, since the anatomy of their urinary tract closely resembles man's in size and intrinsic anatomic protection. Throughout the experimentation the investigators adhered to the principles described in *Guide for the Care and Use of Laboratory Animals,* prepared by the Committee on Care and Use of Laboratory Animals [*19*]. The animals were anesthetized and intubated by a veterinarian with a combination of ketamine hydrochloride (35-mg/kg body weight) and xylazine (5-mg/kg body weight). Flak jackets (Body Armor, Fragmentation Protective Vest, Ground Troop FSN 8470-01-092-8499) were obtained from standard military stock and placed appropriately on the anesthetized pigs so that both flanks were protected. The flak jacket used in this study was made of 13 layers of 1500 denier weight Kevlar.

Each flak-jacket-protected pig was shot once. Projectiles were used from .22 long rifle and .38-caliber revolvers, and from .45-caliber and 9-mm pistols. Additional weapons included a 12-gage, full choke 20-in. (51-cm) barrel shotgun with 00 shot and rifled slug loads, M-14 (.308 caliber) and M-16 (.223 caliber) rifles, and an AK-47 rifle (7.62 mm). Table 1 shows the ballistics data for each of the weapons used in this study. All weapons were fired from a distance of 10 ft (3 m) into the flak-jacket-protected left flank of the anesthetized pig, and only one round was fired per pig. The pigs were allowed to survive the wounding for 60 to 90 min (the average time between wounding and admission to a field hospital during the Vietnam conflict) and then were killed by the intravenous injection of T-61, a potent cardiac depressant.

The flanks were explored to determine the amount of trauma sustained by the kidney and

TABLE 1—*Ballistics data.*[a]

Weapon	Bullet Weight, grains	Average Muzzle Velocity, (ft/s)	Average Muzzle Energy, ft·lbf
.22-caliber long rifle revolver	40	950	80
.38-caliber revolver	158	920	300
.45-caliber pistol	230	820	340
9 mm pistol	115	1345	460
12-gage 00 shot[b]	60.6[b]	1330	238[b]
12-gage rifled slug	545	1330	2140
M-16 rifle (.223 cal)	55	3240	1280
M-14 rifle (.308 cal)	150	2820	2650
AK-47 rifle (7.62 mm)	180	2625	2750

[a]Ballistics data adapted from Refs *20* and *21*.

[b]The 12-gage 00 shot load consisted of 9 pellets in a 2¾-in. (7-cm) shell for a total weight of 545 grains. The total energy for all 9 pellets was 2142 ft·lbf (2902 J).

NOTE: 1 ft/s = 0.3048 m/s and 1 ft·lbf = 1.355 J.

the surrounding tissue. Photographs documented the damage to the flak jacket and the animal. The wounds were evaluated with regard to the following five parameters:

- extent of blunt or penetrating trauma to the flank,
- extent of trauma to the kidney,
- damage to adjacent organs (for example, liver, opposite kidney, great vessels, spinal cord),
- relationship of visible external damage to internal damage, and
- necessity of surgery and the potential survivability.

Results

Table 2 summarizes the extent of penetration seen with each weapon. Bullets from the .22-caliber long rifle and the .38-caliber revolvers, as well as the .45-caliber pistol, caused only minor damage to the flak jacket (Fig. 1). The .22-caliber bullet failed to penetrate the material, while the .38- and .45-caliber rounds lodged in the jacket. In each case the skin

TABLE 2—*Extent of penetration for each weapon fired.*

Weapon	No Jacket Entry	Jacket Entry, No Exit	Animal Entry, No Exit	Animal entry and Exit; Jacket Reentry, No Exit	Perforation of Both Animal and Jacket
.22-caliber long rifle revolver	X				
.38-caliber revolver		X			
.45-caliber pistol		X			
9-mm pistol		X			
12-gage 00 shot		X			
12-gage rifled slug		X			
M-16 rifle (.223 cal)			X		
M-14 rifle (.308 cal)				X	
AK-47 rifle (7.62 mm)					X

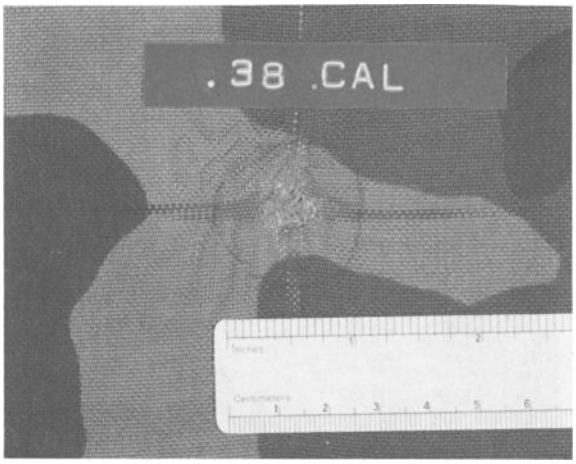

FIG. 1—*Damage caused by entry of .38-caliber bullet into flak jacket. Animal suffered no external or internal damage (AFIP Neg. No. 86-11265).*

was not damaged, and no internal injuries were sustained by the animal. Survivability was considered to be excellent, and there would have been no need for surgery.

The 9-mm pistol, 12-gage 00 shot, and 12-gauge rifled slug produced jacket entry with no exit (Fig. 2), with all three rounds lodging in the jacket. There were superficial cutaneous abrasions, contusions, and lacerations as well as hemorrhage in the underlying muscles (Fig. 3), but no internal damage was noted. Survivability was considered to be excellent with a need for only minor surgical attention.

The M-16 (.223-caliber) round produced jacket perforation with the projectile lodging within the animal. Autopsy demonstrated hemoperitoneum, hemorrhage within the mesentary, multiple fractures of the lumbar vertebra and the lower three ribs (Fig. 4), as well as lacerations of the aorta and the inferior vena cava. There was no visible damage to the genitourinary system. Survival would have been unlikely, but surgery would have been advised if the patient had been alive upon arrival at the hospital.

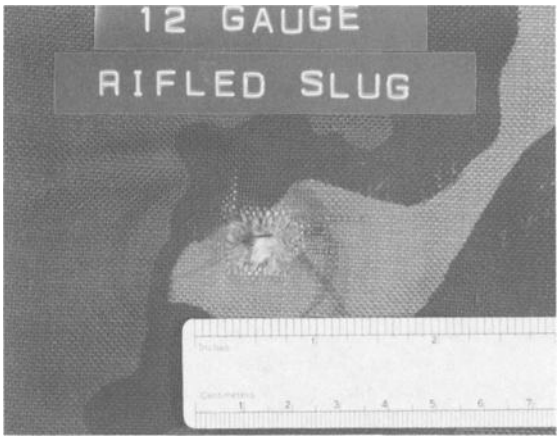

FIG. 2—*Flak jacket damage caused by 12-gage rifled slug (AFIP Neg. No. 86-11263).*

FIG. 3—*Superficial cutaneous laceration following assault with 12-gage rifled slug. Projectile lodged within flak jacket (marker = 1/4 in. [0.6 cm]) (AFIP Neg. No. 86-6916).*

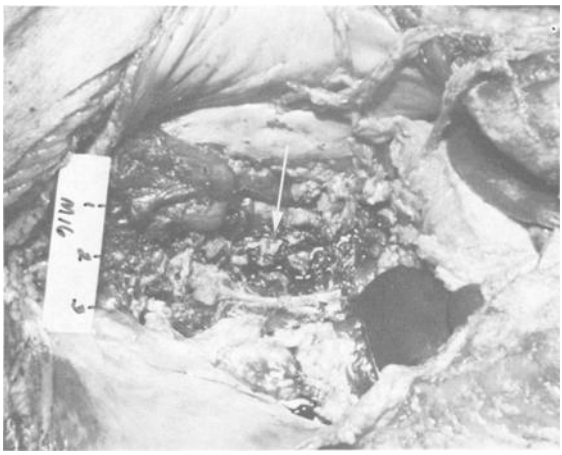

FIG. 4—*Internal damage suffered following trauma with .223-caliber bullet shot from an M-16. Bullet passed through jacket and lodged within animal. Liver lies in lower right-hand side of picture, and thoracic cavity and lung can be seen in upper right-hand corner. Arrow points to fractured vertebral bodies. A large retroperitoneal hematoma, which was the result of lacerations in aorta and vena cava, was evacuated for this picture. Scale is in inches (AFIP Neg. No. 86-6918).*

The M-14 (.308-caliber) missile perforated the flak jacket as well as the animal and lodged in the flak jacket on the opposite side. Autopsy findings included hemoperitoneum, multiple fractures of the mid-lumbar vertebrae, damage to the lumbar spinal cord, and laceration of the vessels, the hilum, and upper pole of the right kidney (Fig. 5). Lacerations were also noted in the lower pole of the left kidney, the small bowel, the lower abdominal aorta, and inferior vena cava. The probability of survival would have been low, and the advisability of surgery would have depended upon the condition of the patient upon arrival at the hospital. The patient would probably have been dead by the time of arrival at a field hospital.

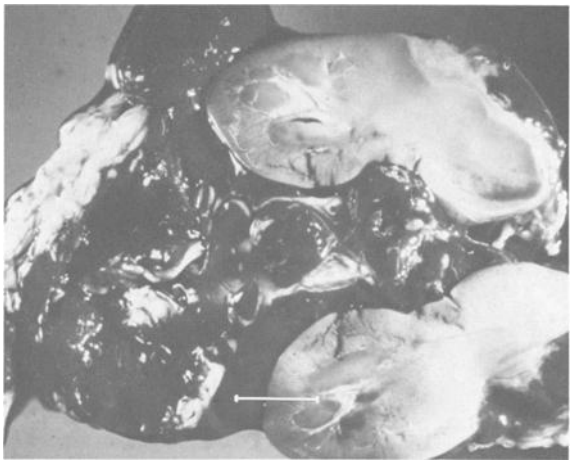

FIG. 5—*Renal trauma and perirenal hematoma secondary to .308-caliber bullet shot from an M-14. Bullet perforated jacket and animal, and lodged in jacket on the other side of the animal (marker = 1 in. [2.54 cm]). (AFIP Neg. No. 86-6917).*

The AK-47 (7.62-mm) round produced a through-and-through perforation of both the flak jacket and the animal. Autopsy demonstrated massive hemoperitoneum (Fig. 6), with laceration of the spleen and both kidneys, and fractures of the upper lumbar vertebrae. The probabilities of survival as well as the need for surgery were considered to be very low.

Discussion

The results of this investigation demonstrate that the flak jacket provides the kidney with good protection against a low-velocity and low-kinetic energy projectile. Of the three low-velocity weapons (less than 1200 ft/s [366 m/s]) only the .38-caliber revolver and the .45-

FIG. 6—*Massive hemoperitoneum after assault by 7.62-mm bullet shot from an AK-47. Projectile perforated jacket and animal (AFIP Neg. No. 86-6913).*

caliber pistol produced damage to the flak jacket. The bullet from the .22-caliber long rifle revolver was unable to penetrate the material.

In the same light, the soft body armor provided adequate shielding against the mid-velocity weapons used in this study (1200 to 2500 ft/s [366 to 762]). The 9-mm pistol, the 12-gage 00 shot, and the 12-gauge rifled slug missiles penetrated the jacket and lodged in the jacket material. The projectiles never entered the animal. The impact caused some minor skin contusions and lacerations, as well as superficial muscle damage, but only minor surgical attention would have been necessary.

The high-velocity weapons in this study (greater than 2500 ft/s) caused severe external and internal injury in spite of the soft body armor. The flak jacket failed to provide protection for the animal during assault with the M-14 (.308-caliber), the M-16 (.223-caliber), and the AK-47 (7.62-mm) rounds. Survival following an injury with one of these weapons would have been highly unlikely.

Conclusion

The flak jacket was not intended to provide protection against direct ballistic insults, but the results from this investigation show that it does provide adequate shielding against low- and mid-velocity bullets. On the other hand, the flak jacket does not have the ability to provide protection against the high-velocity bullets used in this study.

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