Bruce D. Ragsdale,[1] *M.D. and Steven S. Sohn,*[2] *Cdr., U.S. Navy*

Comparison of the Terminal Ballistics of Full Metal Jacket 7.62-mm M80 (NATO) and 5.56-mm M193 Military Bullets: A Study in Ordnance Gelatin

---

REFERENCE: Ragsdale, B. D. and Sohn, S. S., **"Comparison of the Terminal Ballistics of Full Metal Jacket 7.62-mm M80 (NATO) and 5.56-mm M193 Military Bullets: A Study in Ordnance Gelatin,"** *Journal of Forensic Sciences,* JFSCA, Vol. 33, No. 3, May 1988, pp. 676-696.

ABSTRACT: Great controversy has surrounded the replacement of the 7.62-mm caliber by the reduced 5.56-mm caliber as the standard U.S. military rifle. Although its relevance to human wounding can be debated, the terminal ballistics of military small arms in ordnance gelatin remains a convenient medium for comparative testing. In the present study, 7- by 10- by 24-in. (18 by 25 by 61 cm) blocks of 20% ordnance gelatin were fired upon from a range of 19 ft (6 m) under high-speed cinemagraphic surveillance. The tendency of the M193 5.56-mm full metal jacket projectile to break up in soft tissue simulant was confirmed as a fundamental difference from the 7.62-mm M80 NATO ball.

KEYWORDS: forensic science, ballistics, wound ballistics, comparative analysis

Since the 1940s, the trend in military rifles has been towards one of shorter, lighter arms firing smaller caliber bullets at a more rapid rate, facilitated by lighter recoil. In part, this trend is based upon the recognition that most combat targets are engaged at relatively short range, obviating the need for the more powerful ordnance of the past, designed to deliver accurate and effective fire out to several hundred yards. An additional factor has been the shift in battlefield tactics away from accurate shot placement to the concept of fire power, an emphasis on higher rates of fire.

Not all those charged with making small arms recommendations have favored this trend, as reflected in some reference titles [*1*]. The degree of polarization over the proper caliber and power of a military cartridge, in fact, qualifies this as a major controversy in the field of firearms. In this often heated emotional atmosphere, there have been many ill-founded claims and counter claims. Much from one "authority" is repeated by another without analysis, let alone original testing.

An area to be clarified is the ability of the 5.56-mm round to create more severe tissue wounds than the 7.62-mm [*2*], although the later has twice the muzzle energy. This is traditionally attributed to earlier and more rapid "tumbling" of the 5.56-mm bullet along the

---

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of Defense, the Department of the Navy, or of the acknowledged reviewers of the manuscript. Received for publication 29 May 1987; revised manuscript received 10 July 1987; accepted for publication 21 July 1987.

[1] Visiting scientist, Forensic Pathology Department, Armed Forces Institute of Pathology, Washington, DC, and pathologist, Sonora Laboratory Science/ClinPath Associates, P.C., Mesa, AZ.

[2] Chief, Missile Trauma Branch, Forensic Pathology Department, Armed Forces Institute of Pathology, Washington, DC.

wound tract [*3–5*]. Our preliminary shots into tissue simulant and the work of others [*6*] suggested this view is incomplete. Relative wounding potential should be cataloged by specific bullet species and impact velocities rather than weapon type, since an individual firearm can chamber and fire a variety of ammunition. The slightly heavier M855 with internal steel penetrator in the lead core will be replacing the lead cored M193, so it is imprecise to speak of "the M16 bullet." Detailed measurements of temporary and permanent cavities in gelatin are infrequently presented in the existing literature. Against this background, the following experiments were conducted.

Experimental Shots into Ordnance Gelatin with 7.62-mm (M80) and 5.56-mm (M193) Full Metal Jacket Military Cartridges

The 7.62-mm NATO M80 ball cartridges, Lot IVI, were loaded in January 1985 by Valcartier Industries, Inc. The military 5.56-mm M193 ball cartridges were of Remington manufacture, Lot RA 5318. The rifles are military issue in like-new condition: 7.62-mm M14, Ser. No. 652121, and 5.56-mm M16 A1, Ser. No. 4622843.

Standard Velocity Shots from the M-14 and M-16 Rifles

Blocks, 7 by 10 by 24 in. (17.8 by 25.4 by 61 cm), of 20% gelatin (Kind and Knox Pharmagel A, Ordnance Type 250A) were cast by a previously described method [*7*] and fired upon from a range of 19 ft (5.8 m). The impact events were recorded on Kodak 4X Reversal 16-mm film No. 7277 with a Hycam high-speed motion picture camera. Identification of the single frame showing the maximum instantaneous temporary cavity (MITC) permits tracing the outline on paper from its projected image and then obtaining measurements. After firing, total penetration and the depth where maximal internal disruption occurred were determined by viewing the blocks against a strong side light. This depth defines the plane of maximal disruption (PMD), which is then exposed by cross-cutting the block with a taut steel wire. A second cut 0.5 in. (13 mm) shallow to the first produces a slab on which the fissures that radiate from the missile track can be measured. "Major fissures" are defined as those passing full thickness through the slabs. The "total fissure" sum includes all surface fissures exposed on the PMD regardless of depth. These results are diagrammed in Fig. 1, and the responsible missiles are in Figs. 2 and 4.

Behavior of the 5.56-mm M193 Ball at Various Velocities

In our attempt to find the threshold velocity below which the M193 ball will not fragment in 20% ordnance gelatin, the bullets from five rounds were pulled and the same primed cases reloaded with decreasing amounts of gun powder. The three powders used were Dupont SR4759, Hogdon BLC-2, and Hogdon H-380 in individual cartridges. The cartridges were then fired from the 20-in. (51-cm) barreled M16 A1 service rifle into 5- by 5- by 14-in. (12.7- by 12.7- by 35.6-cm) blocks from a distance of 19 ft (5.8 m). By reloading the military M193 Ball into a 22-250 case and firing it from a Ruger Model 77 with 24-in. (61 cm) barrel, an impact velocity of 3700 ft/s (1128 m/s) was attained. The details are presented in Table 1 and illustrated in Figs. 3 and 4.

Behavior of the 7.62-mm M80 Ball at Very High Velocity

Review of the literature suggests that most metallic projectiles, even stainless steel spheres [*8*], will fragment upon striking a soft-tissue, simulant-like gelatin if velocity is sufficiently high. To test this for the 7.62-mm full metal jacket bullet, we pulled two M80 (NATO) balls from military cartridges and reseated them in 300 Wetherby Magnum cases containing 86.0

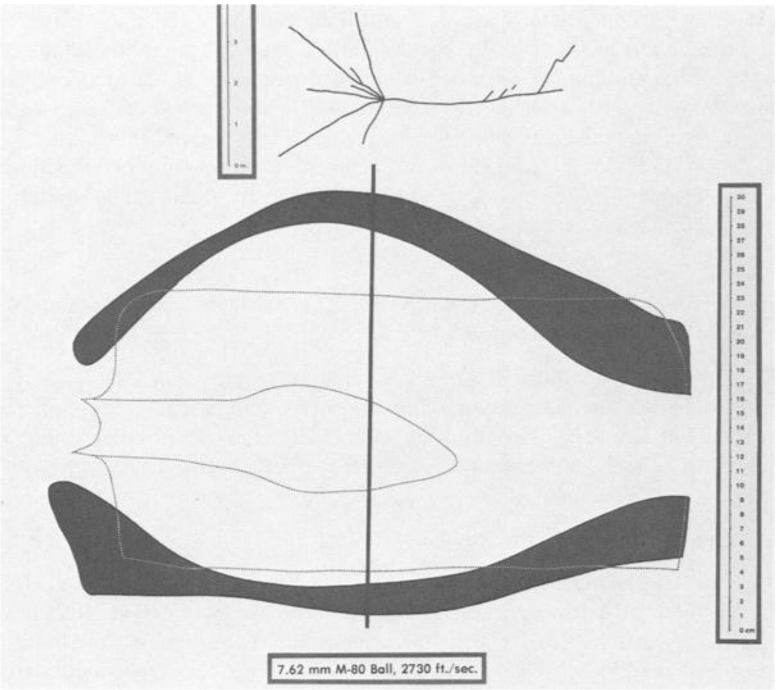

FIG. 1*a—Scale drawings of the developing and maximum temporary cavities in 20% gelatin due to:* (a) *7.62-mm M80 ball at 2730 ft/s (832 m/s), traced from the 40th film frame after impact.*

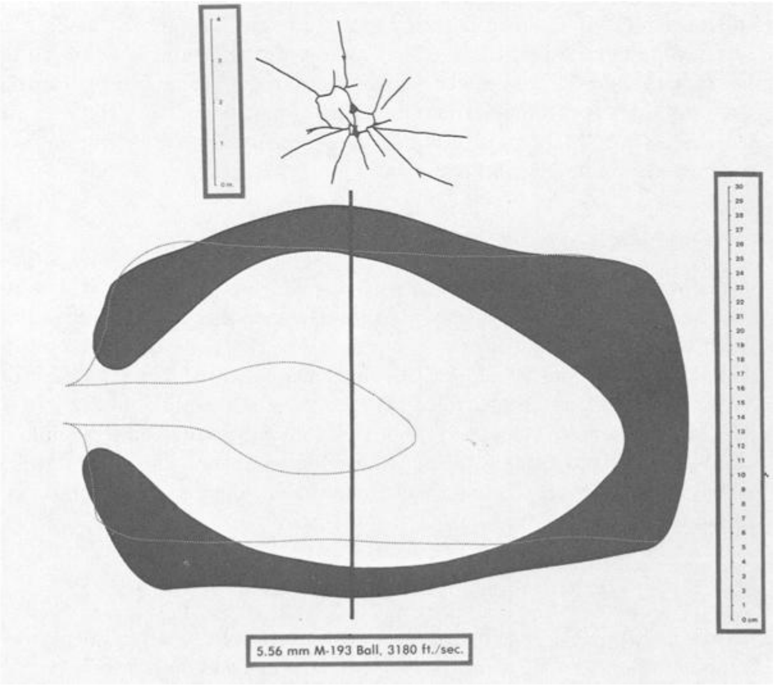

FIG. 1*b—5.56-mm M193 ball at 3180 ft/s (970 m/s), from the 36th film frame after impact.*

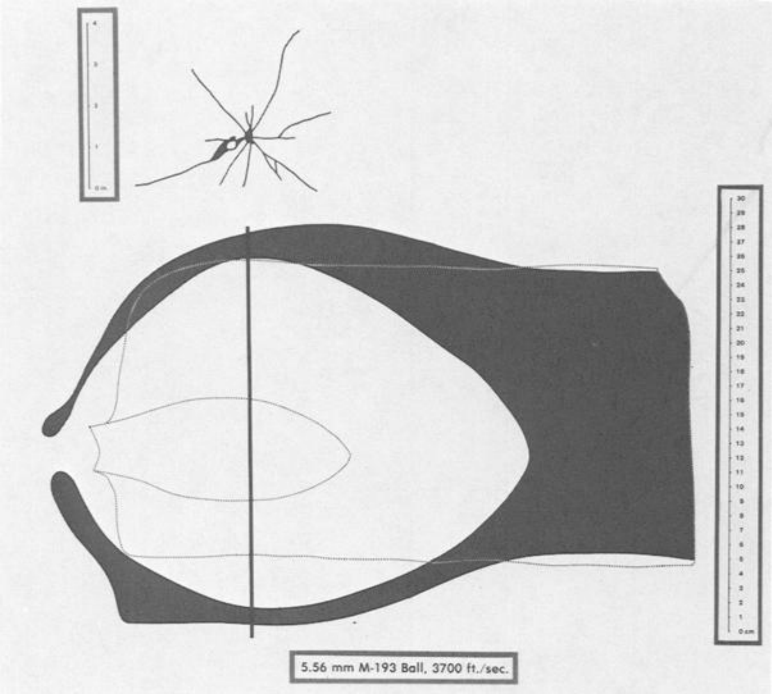

FIG. 1c—*5.56-mm M193 ball at 3700 ft/s (1128 m/s), from the 36th film frame after impact. The corresponding radial fissure pattern at the depths indicated by the dark vertical line (plane of maximum disruption) are drawn to scale at the top of each figure. See Table 2 for measurements.*

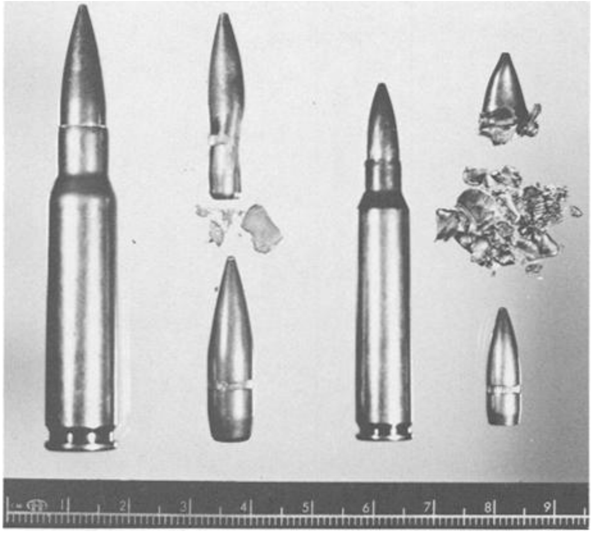

FIG. 2—*The bullets responsible for the impact damage diagrammed in Figs. 1*a *and 1*b *were retrieved by melting down the blocks in hot running water. They are shown above unfired bullets of same caliber. The 5.56-mm bullet responsible for Fig. 1*c *is shown at the right in Fig. 4.*

TABLE 1—*The results of altered striking velocity on the condition of recovered M193 bullets and the permanent cavity in 20% gelatin.*

				Basal Fragments		Tip Fragment			
Velocity, ft/s (m/s)	Total Penetration, in. (cm)	Fragmentation,	T.C.F.	Position in. (cm)	Condition gr.	Position, in.	Condition, gr.	Depth of Plane of Maximum Disruption, in. (cm)	Sum of Radial Fissures in PMD, in. (cm)
3700 (1128)	8.7 (22.1)	yes	P	... ...	M 47.8	...	4.3	3.3 (8.4)	18.9 (47.9)
3067 (935)	10.1 (25.7)	yes	P	6.7 (17.0)	F 13.3	10.1	R38.6	5.5 (14.0)	20.8 (52.8)
2690 (820)	10.3(E) (26.2)	yes	P	10.3 (26.2)	S 15.1	*E* = 10.3	34.3	5.0 (12.7)	12.7 (32.3)
2502 (763)	14.0(E) (35.6)	yes	D	11.0 (27.8)	I 19.4	*E* = 14.0	31.2	5.5 (14.0)	10.8 (27.3)
				Bullet-End	Attitude	%F E.P.	Bullet		
2371 (723)	11.3 (28.7)	no*	I	11.3	PF	I 4.3	49.2	5.5 (14.0)	10.9 (27.8)
2150 (655)	12.0 (30.5)	no*	I	12.0	R	I 2.0	51.4	5.8 (14.7)	11.8 (29.9)

NOTES:

Bullet condition:

S = longitudinally split.
T.C.F. = Trans-cannelure fracture.
P = proximal (toward base).
D = distal (toward tip).
SF = small fragments.
F = coarse fragments.
M = mushroomed (single base fragment = 14.0 gr.).

Deformation:

%F = flattening (% reduction in width at cannelure compared with an unfired bullet).
*EP = extruded lead particle.
I = Intact.
gr. = grain (1 gram = 15.43 grains).

Position/attitude:

E = exited block at *depth* specified.
PF = point forward.
R = reverse (180-deg yaw; base forward).

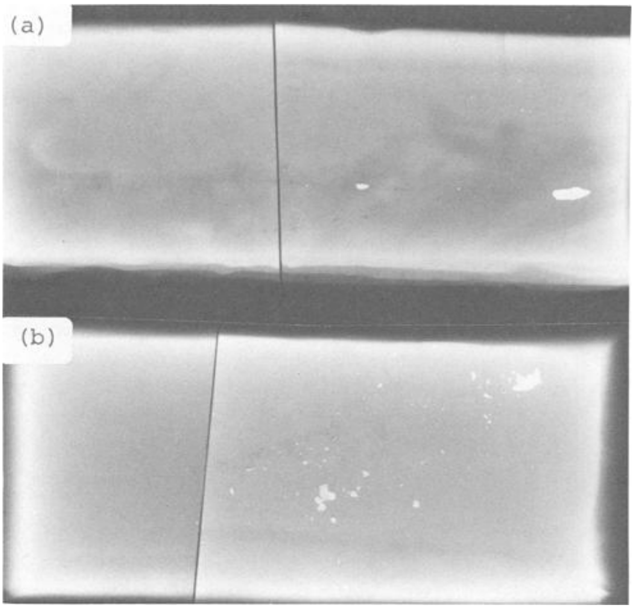

FIG. 3—*Post-shot block radiographs, 5.56-mm M193 from M16.* (a) *The bullet entered from the left at 2371 ft/s and extruded a small amount of lead core near the middle of the "wound channel." The unruptured metal jacket is to the left in point-forward attitude. The bullet is third from the left in Fig. 4.* (b) *The M193 bullet at standard velocity fragmented near the center of the block. The relatively intact tip portion rose from that point, coming to rest in point backwards position* (extreme right); *the bullet is second from the right in Fig. 4.*

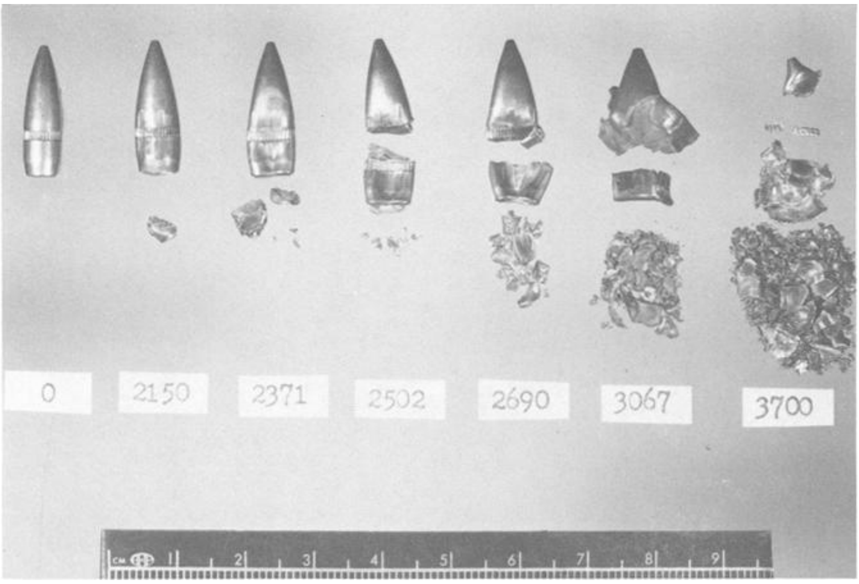

FIG. 4—*Condition of M193 balls retrieved from 20% gelatin blocks after impacting at the velocities indicated (ft/s).*

and 83.0 grains of Dupont 4350 powder and primed with Federal No. 215 Magnum primers. These cases are 2.825 in. (7.176 cm) long, 0.810 in. (2.057 cm) longer than military-issue 7.62-mm cases and have substantially more powder capacity (Fig. 5*a*). The reloaded rounds were fired through chronographic screens into 20% gelatin blocks (Fig. 5*b*) from a Weatherby 300 Magnum rifle with 24-in. (61-cm) barrel.

Full Automatic Firing with the M16

The full automatic cyclical rate for this weapon is between 700 and 800 rounds per minute. A ten-shot full automatic burst from bench rest position can be contained within a 2-in. (5.1-cm) width at a range of 26 ft (7.9 m). The ten perforations on paper form a broad U-shape figure descending slightly to the left, perhaps as a result of the force of brass ejection toward the upper right. This unexpected tight grouping of hits on full automatic led to the attempt to film a sustained full automatic burst on a standard 5- by 5- by 14-in. (12.7- by 12.7- by 35.6-cm), 16.8-lb (7.2 kg) gelatin block (Fig. 6). Six rounds were loaded and fired.

Firing upon Long Bone Segments Encased in 20% Gelatin

Experimental shots from the 7.62- and 5.56-mm military rifles were fired into 5.0- by 5.7- by 12.0- and 5.0- by 5.5- by 6.9-in. (12- by 14.5- by 30.5- and 13.5- by 13.5- by 17.5-cm) 20% gelatin blocks containing human distal femoral segments embedded 1.7 in. (4.3 cm) deep to

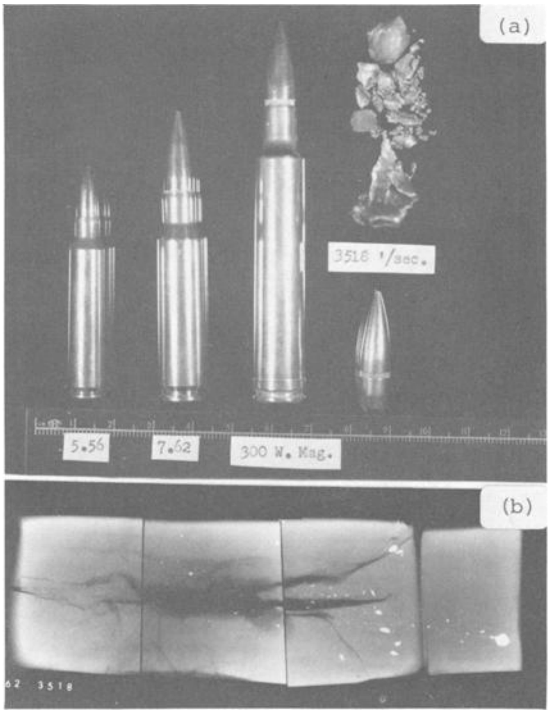

FIG. 5—(a) *The 5.56-mm and 7.62-mm cartridges are dwarfed by the 300 Weatherby Magnum loaded with the M80 ball. To the right are an unfired bullet* (bottom) *and the shattered remnants recovered from the block shown in Fig.* 5b. (b) *An X-ray of the target block shows metallic debris in the distal* (right) *"wound track" and marked fissuring* (dark areas) *due to the M80 at 3518 ft/s.*

FIG. 6*a*—*M16 in full automatic mode: Two consecutive frames from the Hycam 16-mm high-speed motion picture show: early penetration* (top) *and 4-in. (10.2-cm) long tubular "neck" region and tilted ellipsoid configuration of the emerging temporary cavity in the zone of bullet breakup* (bottom).

FIG. 6*b*—*The 15th frame shows the 5.5-in. (14.0-cm) diameter MITC which decompressed downward through a radial fissure that reached the undersurface.*

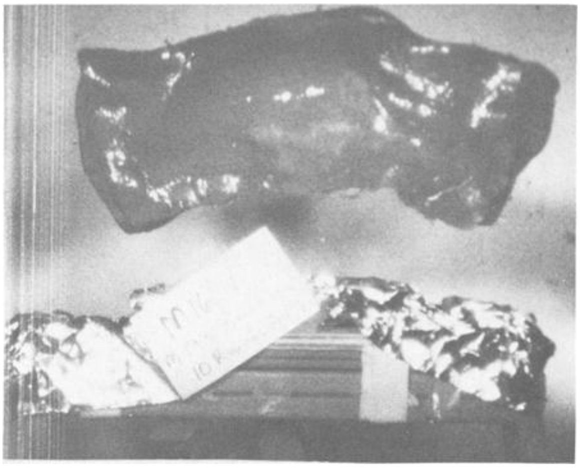

FIG. 6c—*The 160th frame shows the gelatin block rising into the air as a result of the expansile forces of temporary cavitation from the first round. Portions of the ruptured 0.5-in. (1.3-cm) thick plywood table top are seen below.*

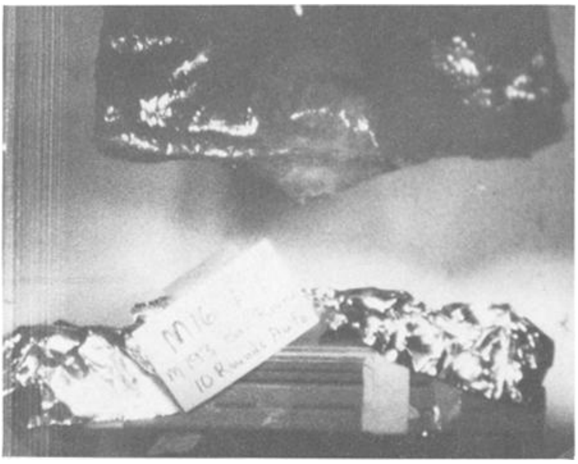

FIG. 6d—*The 266th frame in which the gelatin block is 5.1 in. (13.0 cm) above the table as the second full automatic round, visible as a streak, passes beneath.*

the block face. The targets were radiographed after impact, and then the bone fragments were freed in a stream of hot running water. The broken bones were macerated in 3% sodium hydroxide, defatted in ether, and reassembled with monofilament nylon line and cyanoacrylic glue. The impact defects in cortex and the number of reconstituted fragments were counted (Figs. 7 and 8).

Results and Discussion

Shots into 7- by 10- by 14-in. (17.8 by 25.4 by 35.6 cm) Blocks of 20% Ordnance Gelatin (Table 2)

Temporary Cavitation—The 7.62-mm M80 ball created a MITC 1.2 in. (3.0 cm) larger in diameter than the 5.56-mm M193 ball at military rifle velocities. Both bullets create an early developing temporary cavity with a proximal "neck" region in early film frames (Fig. 6*a* and Fig. 1, Table 2), but unlike soap targets [*9*], these regions subsequently expand to rather large diameters; for the same reason, possibly the relative rate of expansion, the ultimate dilatation of neck regions is under represented by radial fissure measurements. This is a major discrepancy between the actual (Hycam) MITC and the distention predicted by the Wound Profile Method [*10*].

The greatest diameter of the temporary and maximal gelatin disruption were located approximately 1 in. (2.54 cm) closer to the entrance face for the 5.56-mm compared to the 7.62-mm.

Our 5.56-mm MITC diameter of 19.4 cm exceeds Orlowski's [*11*] maximum of 15 cm, but his work was done at 100 m and in 4.7- by 6.7-in. (12- by 17-cm) 20% gelatin blocks. Smaller blocks tend to rip out laterally to decompress prematurely the developing cavity. This occurred with the full automatic shot shown in Fig. 4, but not with the larger block shown in Fig. 1*b*.

The maximal diameter of the MITC as a result of the 3700-ft/s (1128-m/s) M193 from the 22-250 was almost as large as that caused by the 7.62 mm, and was located at a much shallower depth than either the 7.62 mm or the M193 at standard M16 velocity. The M193 striking at 3700 ft/s (1128 m/s) underwent earlier bullet breakup, creating an ellipsoidal early (fourth frame) temporary cavity lacking a "neck" zone (Fig. 1*c*). The maximum temporary cavity was 0.9 in. (2.3 cm) larger in diameter and 4.9 in. (12.4 cm) foreshortened compared to the standard M16 velocity M193. Combined major radial fissures were 1.8 in. (4.6 cm) longer in the PMD than with the M16 shot and only 0.5 in. (1.37 cm) shorter than for the M14's M80 ball. Foreshortening of the temporary cavity as an effect of increasing velocity above a certain threshold has been repeatedly demonstrated [*8,12*].

Radial Fissuring—The 7.62-mm ball created maximal radial fissuring within the gelatin block at a depth of 7 in. (17.8 cm) consisting of five major fissures with a combined length of 14.5 in. (36.9 cm). The PMD was shallower (5.8 in. [14.7 cm]) with the 5.56-mm ball, consisting of five major full thickness fissures with a combined length of 11.4 in. (29 cm). The six major radial fissures as a result of the 3700-ft/s (1128-m/s) M193 sum nearly equal the 7.62 mm, and the PMD was 3.7 in. (9.4 cm) closer to the front of the target. If all radial fissures within a ½-in.-thick (1.27 cm) slab of gelatin in the PMD are summed (not just those evident on the cut surface), the 3700-ft/s M193 (combined length of 24.4 in. [61.9 cm]) exceeds the 7.62-mm M80 at standard velocity (22.0 in. [55.9 cm]).

The PMD was within a centimetre of the depth at which the MITC diameter was maximal for both 5.56-mm shots. For the 7.62 mm, the PMD was 3.4 cm (1.4 in.) beyond the widest girth of the MITC.

Total Penetration—The 7.62-mm ball came to rest in point backwards attitude (175° yaw) after penetrating 20.8 in. (52.8 cm) of 20% gelatin. The bullet's basal segment was narrowed to a thickness of 0.2 in. (5 mm), maximal at the cannelure, from its original nearly 0.32 in.

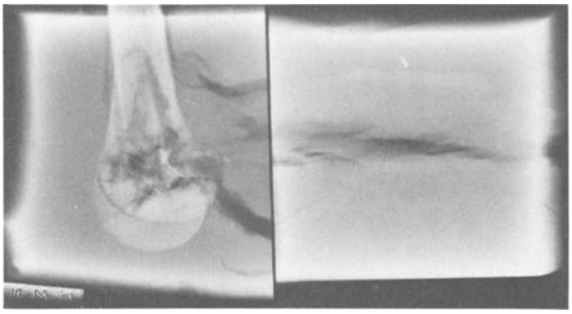

FIG. 7a—*Effect of a 7.62-mm M80 (NATO) ball from the M-14 rifle at 2789 ft/s (850 m/s) on a distal femur encased in a 5- by 5- by 14-in. (13- by 13- by 36-cm) block of 20% ordnance gelatin: A lateral radiograph of the target after the test shot indicates extensive fracturing of the bone which was positioned 1.7 in. (4.2 cm) from the block face. Large radial fissures reach the surface of the block to the left of the bone. A very few small metallic fragments remain in the block from the missile which exited to the right.*

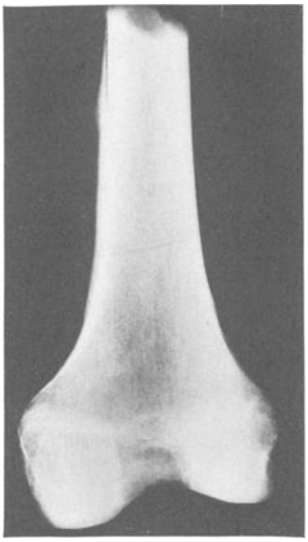

FIG. 7b—*An anteroposterior view of the target bone prior to the test shot shows the delicate internal cancellous bone pattern and surrounding thick cortex. Compare with Fig. 7c.*

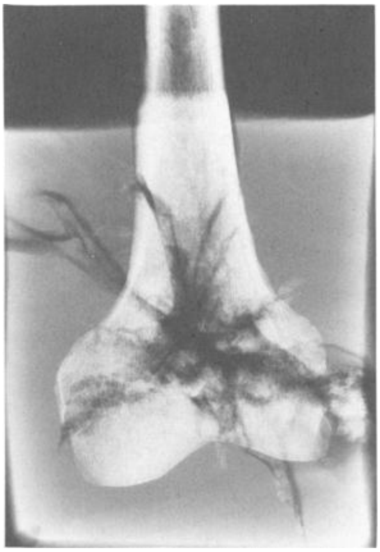

FIG. 7c—*A radiograph of the gelatin encased femur after the test shot shows extensive fracturing and indicates the bone fracture lines are continuous with the radial fissures through gelatin. (Note: the gelatin block was trimmed slightly in height and width before X-ray for clarity.)*

FIG. 7d—*Anterior view of the target bone after freeing from the gelatin, maceration and assembly from 30 fragments. At the top of the anterior cortical defect is a 0.33-in. (8.40-mm) diameter half circle that represents the precise entrance site of the missile.*

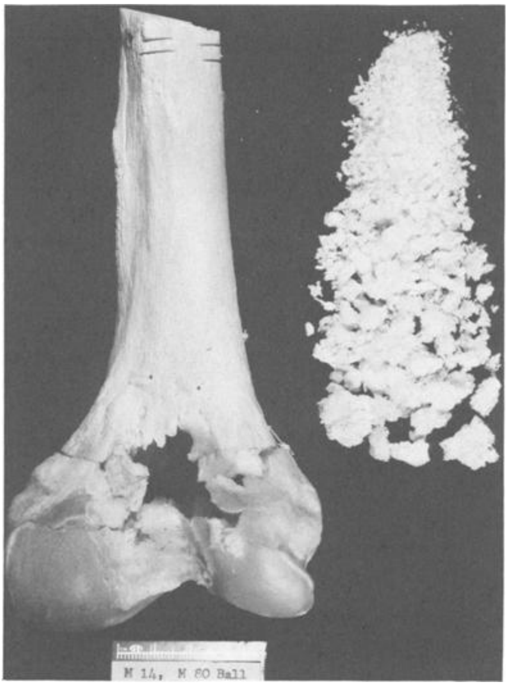

FIG. 7e—*Posterior view of the target bone after assembly shows the residual posterior cortical defect. At its extreme top is a roughly circular perforation representing the precise site of exit of the missile, only slightly larger in diameter. To the right are the bone fragments that could not be reassembled, preponderantly internal (cancellous) material.*

(8 mm), width, associated with extrusion of 6.5 grains of lead from its open base. It is clear that the deforming forces were concentrated at its base and focused on the cannelure (Fig. 2).

The 5.56-mm ball from the M16 split circumferentially at the cannelure into a 32.7 grain flattened but intact tip fragment and a multitude of lead and copper jacket fragments representing the base. The tip exited the side of the block at 15.0 in. (38.0 cm); the main fragments from the base were scattered at along a 5.5 in. (14.0 cm) zone centered at a depth of 5.9 in. (15 cm).

5.56-mm M193 Bullet Performance at Various Velocities—Because of differences in rifling spin forces, reducing the powder charge is an imprecise simulation of extended range [*9*]. However, it is more expedient for precise shot placement on a 5-in. (12.7-cm) square gelatin block face and less challenging technically when it comes to filming the event.

The reduced velocity experiment paralleled prior findings[3] that the threshold for M193 bullet breakup was approximately 2500 ft/s (762 m/s). In each instance, and in many other shots on previous occasions, the repetitive pattern is circumferential fracture through the cannelure with extrusion of a variable amount of lead core from the two fragments (Fig. 3). This occurs rather indiscriminately at either the proximal or distal margin of the cannelure, but determines an approximately 5 grain difference in ultimate tip fragment weight. Relatively more lead extrudes from the basal fragment than the tip, and this also has a relationship to strike velocity. At 2700 ft/s (823 m/s) and above, the basal fragment jacket unwinds

---

[3] M. L. Fackler, M.D., personal communication, Feb. 1986.

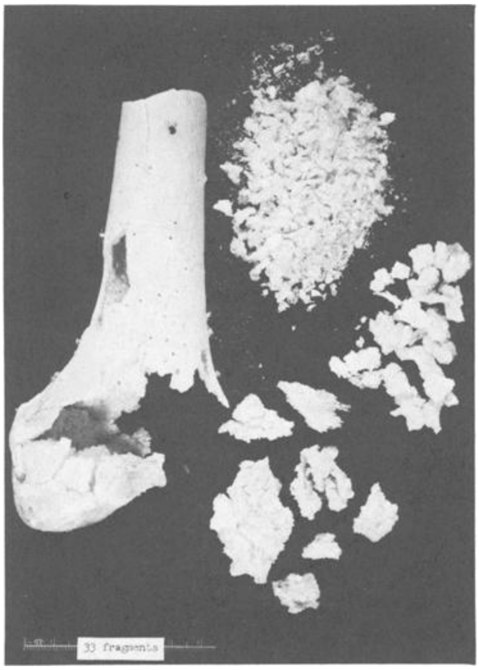

FIG. 8—*Effect of a 5.56-mm M193 ball from the M-16 rifle at 3211 ft/s (979 m/s) on a distal femur encased at a depth of 1.7 in. (4.2 cm) from the bullet entrance face within a 5.3- by 5.3- by 6.9-in. (13.5- by 13.5- by 17.5-cm) block of 20% ordnance gelatin; anterior view of the target bone after removal from gelatin, maceration, and reassembly from 33 fragments. The right end of the bone was fragmented beyond the ability to reconstitute it, resulting in a large segmental defect. (Note: Additional views of this test shot can be found in Ref* 16.*)*

like a ribbon, freeing the core lead entirely. The tip fragment, if contained by the block, is generally rotated 180° (point backwards), a familiar radiographic signature for the M193 in human wounds [*13*].

At 3700 ft/s (1128 m/s), the bullet broke circumferentially at the cannelure; apparently its 14.0-grain basal fragment had sufficient velocity to be flattened into a flower petal appearance resembling a completely mushroomed soft point bullet (Fig. 4). The bullet body was reduced to minute particles sparing an intact 4.3-grain tip fragment. The entire body of the missile had apparently fragmented subsequent to transcannelure fracture.

The decline in velocity of 55-grain 0.223-caliber bullets with increasing range is given in Table 3, as adapted from the Sierra reloading manual [*14*]. With an initial velocity of 3100 ft/s (945 m/s), the velocity loss over the first through fourth 100-yard (90 m) segments of flight would be 344, 340, 316, and 290 ft/s (104.9, 103.6, 96.3, and 88.4 m/s), respectively.

It was also evident that powder charges at and below the amount required to achieve 2500 ft/s (762 m/s), the approximate breakup threshold in gelatin, were inadequate to operate the M16's unusual direct gas action mechanism to eject the spent case.

7.62-mm M80 Ball Performance at Very High Velocity—From the Weatherby, impact velocities of 3584 and 3518 ft/s (1093 and 1073 m/s) resulted in irregular longitudinal fractures rupturing the gilding metal jackets along their sides (Fig. 5). Thus freed, the lead cores were reduced to a multitude of small fragments. The lines of jacket rupture were unrelated to cannelure grooves and portions of the basal opening were easily identified; that is, the base

TABLE 2—*Perameters of the temporary and permanent cavities in 20% gelatin blocks.*

		"Neck" Region		Maximum Instantaneous Temporary Cavity				Plane of Maximal Disruption		
									Radial Fissure Sums	
Bullet	Approximate Striking Velocity ft/s (m/s)	Length, in. (cm)	Diameter, in. (cm)	Maximum, Film Frame	Depth, in. (cm)	Width, in. (cm)	Total Penetration, in. (cm)	Depth, in. (cm)	Major, in. (cm)	All, in. (cm)
7.62-mm M-80	2730 (832)	3.1 (8.1)	1.5 (3.8)	40	5.7 (14.2)	8.8 (22.4)	20.8 (52.8)	7.0 (17.8)	14.5 (36.9)	19.7 (50.1)
5.56-mm M193	3180 (969)	2.1 (6.5)	1.0 (2.5)	36	5.5 (14.0)	7.6 (19.4)	13.8 (35.1)	5.8 (14.8)	11.5 (29.1)	22.3 (56.6)
5.56-mm M193	3700 (1128)	...	...	36	3.7 (9.4)	8.5 (21.6)	8.7 (22.1)	3.3 (8.4)	14.1 (35.7)	18.9 (47.9)

TABLE 3—*Decline of projectile velocity and energy with range* [14].

Range	5.56-mm 55 gr.		7.62-mm 150 gr.	
	Velocity, ft/s	Retained Energy	Velocity, ft/s	Retained Energy
Muzzle	3100	1173	2800	2611
100	2756	927	2568	2196
200	2416	713	2348	1835
300	2100	539	2138	1522
400	1810	400	1939	1253
500	1531	286	1749	1019
600	1296	205	1558	809
1000	876	94	1047	365

did not disintegrate completely. The pointed bullet tips were not preserved nor recognizable by target radiograph nor direct inspection. Maximum penetration of the most distal metallic fragments were 22.5 and 16.4 in. (57.2 and 41.7 cm), respectively, for the two extreme velocity shots.

Full Automatic Firing of the M-16—The effort to film multiple sequential hits was unsuccessful because the 14.5-in. (36.8-cm) long, 16.81-lb (7.2-kg) block was blown vertically off the plywood table by the 5.5-in. (13.9-cm) diameter maximum temporary cavity from the first 3210-ft/s impact. The block was 5.1 in. (13.0 cm) above the table top when the second full automatic round passed beneath (Fig. 6). The single bullet that struck was shown to have hit centrally, fragmented, and penetrated to a depth of 12¹/₄ in. (31.1 cm). The zone of maximal disruption was between 4 and 11 in. (10.2 and 27.9 cm).

The Gelatin/Bone Targets—The 7.62-mm ball entered the target block at 2789 ft/s (850 m/s), passed through the distal femoral metaphysic creating a 0.4- by 0.8-in. (1.0- by 2.0-cm) entrance defect and a 0.7- by 1.1-in. (1.8- by 2.8-cm) exit defect in anterior and posterior cortices, respectively, as defined by pieces missing after reassembly as far as possible (Fig. 7*d* and *e*). Hemicircumferences of the actual bullet perforations of cortex could be found on anterior and posterior cortices; these diameters were the same, 0.33 in. (8.40 mm), an indication that the bullet remained stable through the bone. The bone was reassembled from 30 fragments. The intact missile exited the test target, which was markedly lacerated along its sides consistent with a massive temporary cavity. The post-shot radiograph confirmed the missile did not fragment to any significant degree (Fig. 7*a*).

The effect of the 5.56-mm ball entering at 3100 ft/s (945 m/s) was to create a 2.4- by 1.5-in. (6.0- by 3.7-cm) anterior cortical entrance defect and a 1.6- by 1.5-in. (4.0- by 3.7-cm) exit defect. The bone was reconstituted from 33 fragments, but substantial amounts of cancellous bone and fine cortical fragments could not be repositioned. One condyle was entirely disintegrated. The reconstituted specimen (Fig. 8) closely resembles the large segmental defects in bone reported by Robens [*15*] with the M16. A "lead storm" shown by the post-shot radiograph indicated breakup of the bullet, and a small trail of gelatin in the high speed motion picture film marked the exit trail of the intact tip fragment (see Fig. 4 in Ref *16*).

Relevance of Tissue Simulant Studies to Human Wounding

Temporary Cavitation

The relative importance of temporary cavitation to tissue injury remains unclear and is probably overemphasized. This is because some tissues, notably skeletal muscle, can withstand substantial momentary stretch and return to normal position because of inherent elasticity and suffer minimal damage. A solid bullet would be expected to cause only an inconsequential tubular cavity in aerated lung, unless there are secondary missiles, such as shattered rib fragments. At the other extreme, inelastic tissues (for example, liver and spleen) are likely to be pulped by substantial cavitational forces. Therefore, the symmetrical tubular, conical, or elliptical temporary cavities familiar in ordnance gelatin cannot be superimposed upon torso models as an indication of what would or would not be injured by a given wound. This difference may underly the dissatisfaction of combat veterans [*17*] with bullet effectiveness ratings (for example, the Relative Incapacitation Index) [*18*] that are based on simulation and urges caution rather than overconfidence [*6*] when drawing conclusions about wound management.

The maximum instantaneous temporary cavity diameters displayed by our gelatin blocks cannot be assumed to be equivalent to those that would occur in living soft tissue, nor should it be surprising if they differ from the experimental results of others. This is because temporary cavity size varies with the dimensions of target blocks, gelatin consistency (for example, 20 versus 10%) and perhaps mix temperature [*19*].

Radial Fissures

The displacement of a ballistic pendulum on which a standardized gelatin block is shot has been found to provide more acceptable measurements of kinetic energy deposit than high-speed photography of the temporary cavity formed [*20*]. Although this may satisfy adherents of the energy deposit theory of wounding, it does not detail how the energy is expended along the wound track and is therefore of less interest to surgeons and pathologists.

Radial fissures in gelatin have their counterpart in tissue wound tracks and contribute substantially to the zone of blood leakage. The latter is important in combat since only two factors—acute blood loss and significant central nervous system disruption or shock—are likely to terminate determined aggression.

Viewing the surface of radial fissures in oblique light indicates they have an irregular steplike surface resembling fracture surfaces of a brittle substance. This suggests they may form not so much as the consequence of stretch, but by shatter more analogous to the breaking of ice (Fig. 7*c*). Those who prefer the synonyms "cracks" or "fractures" [*21*] to "fissures" may be using more precise terms. If impacting bullets impart a widening cone of shatter force, this may supplement bullet deviation from perfect end-on attitude (yaw) and bullet deformation in explaining why minimal fissuring is generally found in proximal portions of pistol and rifle bullet tracks alike, even those for which high-speed photographs show marked distension of the instantaneous temporary cavity extending to the entrance block face.

That the 5.56-mm bullet can cut away free chunks of target substance has been previously noted [*21*] and would place the undebrided wound at increased risk for severe infection [*15*]. In accord with the findings of Fackler [22], in this project and in many previous shots involving special purpose handgun ammunition, we have only found completely free chunks of target substance along gelatin "wound tracks" in instances where the responsible bullets fragmented (Figs. 1*b* and 1*c*).

Terminal Ballistics and the Physics of Variation in Performance

Bullet yaw, the angular deviation of a bullet from perfect end-on attitude, tends to decrease during flight in the air as a result of the gyroscopic force of spin imparted by riflings within the barrel. However, any residual yaw angle tends to increase markedly as tissue is penetrated because the spiraling force is inadequate to maintain stability in tissue, a medium 800 times as dense as air. A yawing bullet presents an increasing frontal surface area to the target substance, and this increases the rate of energy transfer.

The greater the stability of an elongated bullet in the target, the longer the "neck" region of the wound profile in gelatin [*10*] and in an inelastic media such as soap [*9,23*]. However, the depth of penetration into target simulant to the point where rapid yaw begins is quite variable for the two weapons under study, even with ammunition from the same box [*20*]. This is because the tendency to overturn in tissue or tissue simulant is multifactorial, including even such details as minor irregularities in symmetry and internal weight distribution.

A lighter elongate bullet will destabilize sooner than a heavier one with the same spin stabilization [*24*]. This partially explains why the "neck region" for the 5.56-mm M193 is shorter on average than for the 7.62-mm M80. There are other factors, however, such as the overturning moment which favors earlier upset of shorter bullets [*9*].

Retardation, the degree to which a bullet is slowed by drag, is relatively greater for a fast, small missile, both attributes of the 5.56 mm [*25*]. More rapid deceleration favors a higher rate and proportion of energy transfer. It would also increase the strain on the body of a steeply yawing bullet and, in the case of the M193, contribute to the tendency to fragment.

All of these variables combine to explain the variation in the length of the "neck zone" before bullet upset and maximal performance. Current literature makes altogether too much of velocity [*26*]. The M16's 55-grain M193 with a muzzle velocity of 3200 ft/s (975 m/s) carries 1250 ft · lb (1694 J) of energy. This is about half that of the M14's 150-grain M80 at 2750 ft/s (838 m/s). Obviously, the difference in velocity is not the only explanation of the differences seen in gelatin. For the M16's M193 ball, fragmentation is an important factor.

The symmetrical damage revealed in homogeneous translucent gelatin can be expected to be substantially modified if the incoming missile is destabilized by an intermediate target [*27*] or strikes bone early in its penetration. Also, the complex structure of the human body has layers of variable density (skin, fat, muscle, fascia), and irregularly shaped viscera and visci variously filled with air and fluid. This complexity means there will be an almost infinite array of possible wound channel configurations, unlike those in homogeneous tissue simulant. Also, a shot through a thin portion of the body such as the foot or forearm may result in a narrow perforating channel corresponding to the "neck" region in gelatin and not the expected devastating wound [*6*]. With greater thickness to the target or oblique extremity hits, fuller expression of bullet performance is more likely (Fig. 1*b*).

Penetration and Weight Retention

A bullet's ability to penetrate is a tactical advantage against a barricaded or armored adversary. But highly penetrating bullets tend to perforate their targets, expending only a fraction of their energy on internal damage. Beyond this consideration of efficiency, there is the issue of overpenetration being a hazard to bystanders. As anti-terrorist actions became more common, this long-standing concern of civilian law enforcement is increasingly shared by the military.

It has been pointed out by a veteran combat surgeon and ballistician that missile fragmentation connotes severe injury [*22*]. The converse of this would be that, given the same weight and striking velocity, a fragmenting bullet will inflict more damage than a nonfragmenting solid. A physical explanation for this is that energy transfer occurs across contacting surfaces [*28*]. Multiple smaller particles have a much greater total surface area than the single solid from which they derive and can therefore transfer energy at a more rapid rate. The munitions designer's goal of an expanding bullet that stays in one piece during penetration is a legacy from big-game hunting where thick skin and substantial muscle and bone must be penetrated to reach vital centers and does not apply to unarmored men.

Importance of Range and Impact Velocity

Upon leaving the rifle barrel, a bullet is no longer subject to the acceleration of burning gun powder and begins at once to slow down. The rate of deceleration during flight in air is greater for bullets of higher initial velocity and lower mass [*29*]. Because of this, the light and swift 5.56-mm M193 ball has proportionately less residual velocity at ranges over 50 yd (45 m) than the 7.62-mm M80 (Table 3). At 100 m (110 yd), the M14 was found to cause more severe tissue wounds than the M16 two thirds of the time [*2*]. At 1000 yd (900 m), the 5.56-mm missile will have less than a third of the energy retained by of the 7.62 mm (Table 3).

A major change in M193 performance should be anticipated at 175 yd (160 m), where its residual velocity from a 20-in. (50.8-cm) M16 barrel will be below the approximate 2500-ft/s (762-m/s) threshold of fragmentation. Of potential forensic science importance would be the range of fire information available in the condition of the recovered bullet (fragmented or nonfragmented, as well as details about the fragments) in those cases where no bone is struck to be blamed for fragmentation. In any event, the disintegration of the basal portion of the M193 ball obscures forensically important rifling impressions on the copper jacket.

Full Automatic Firing

A forensic science significance of the full automatic experiment is that a wound to a head or extremity that was resting against a rigid surface (such as earth, floor, or wall) is unlikely to be the result of multiple hits from an aimed automatic burst. This is because the body part would tend to rebound out of the path of subsequent bullets as a result of the forces of cavitation unless followed by the muzzle.

Gelatin/Bone Target System

This simulates an extremity hit since long bone segments are normally surrounded by variable amounts of elastic soft tissue. More than half of combat casualties involve extremity hits. Therefore, the gelatin/bone target probably has more relevance to human wounding than a plain gelatin block, since the latter cannot be compared to the complex regional density differences within the body. The 4.2-cm thickness of gelatin before the bones was chosen so as to place them at a depth where the effects of bullet upset might begin to be apparent. A similar relationship could obtain in vivo with an oblique entry, but in point of fact, the soft tissue over the anterior distal femur is usually only half this thickness. The central metaphysis is a compromise point of impact because it is known that diaphyses (shafts) are more brittle, tending to separate into large fragments that act as potent secondary missiles; the dominantly cancellous bone of epiphyses (ends) tends to give way, leaving more discrete channels [*30*].

In the present experiment, the 0.33-in. (8.40-mm) diameter perforating wound track of the 7.62-mm ball (which passed through relatively intact) contrasts with the massive defect due to the 5.56-mm M193 ball which fragmented. This agrees with Robens [*15*], who found that military 7.62-mm bullets create discrete perforations or spiral fractures when striking proximal tibial metaphyses from 30 m. In contrast, high-velocity missiles (for example, the 5.56-mm M193) create segmental losses in addition to discrete fractures. The primary central defect where both cortex and spongiosa are pulverized is surrounded by a second disorganized fragmented zone about 3 cm wide. Beyond this is an outer (third) zone where spiral or stellate fracture lines run proximally and distally up to 10 cm. The more abundant secondary missiles help explain the more devastating effect on surrounding soft tissue in which there is three to four times the amount of immediate loss.

Conclusions

1. Fragmentation of the 5.56-mm M193 ball helps account for accentuated target disruption at a shallower depth compared to the 7.62-mm M80 ball, which at proximal range carries twice the energy.

2. Wound profiles calculated from radial fissure lengths in gelatin [*6,10*] more closely resemble the wound tracks in inelastic soap [*9*] than they do the actual high speed record of the MITC in 20% gelatin. This is because the early "neck" portions of the permanent wound track participate significantly in the MITC, a fact not obvious from simple examination of a gelatin block after test firing.

Acknowledgments

The authors wish to thank the following individuals for their suggestions and review of the manuscript: Mr. Robert Lutz, Instructor of Ballistics, U.S. Service Training Center, Beltsville, MD; Mr. Edward C. Ezell, Curator, Division of Armed Forces History, Smithsonian Institution, Washington, DC; Frank Johnson, M.D., Chief of Chemical Pathology, Armed Forces Institute of Pathology, Washington, DC; and Carolyn M. Ragsdale, R.N., Paso Robles, CA.

Col. Fackler's suggestions on experimental design are acknowledged. High-speed photography was by Mr. Joseph J. Durick. Still photography was by Mr. Luther Duckett, Ms. R. J. Ferris, and Mr. Steve Ferendo. Reloading for the variable velocity experiment was by Mr. David H. Morse and also Mr. Dale Mette of Atlantic Guns, Silver Spring, MD. Ms. Eileen Rusnock assisted in bullet weighing and preparation of prints. Mrs. Randy Perse prepared photographic prints. The manuscript was typed by Mrs. Elizabeth Ergueta and printed by Mrs. Marilyn Davis.

References

[*1*] Ezell, E. C., *The Great Rifle Controversy*, Stakpole, Harrisburg, PA, 1986.

[*2*] Tikka, S., Cederberg, A., Levanen, J., et al., "Local Effects of Three Standard Rifle Projectiles in Live Tissue," *Acta Chirurgica Scandinavica, Supplement*, Vol. 508, 1982, pp. 61-77.

[*3*] Barach, E., Tomlanovich, M., and Novak, R., "Ballistics: A Pathophysiologic Examination of the Wounding Mechanisms of Firearms: Part I," *Journal of Trauma*, Vol. 26, 1986, pp. 225-235.

[*4*] Barach, E., Tomlanovich, M., and Novak, R., "Ballistics: A Pathophysiologic Examination of the Wounding Mechanisms of Firearms: Part II," *Journal of Trauma*, Vol. 26, 1986, pp. 374-383.

[*5*] Miller, M. L., "Soviet Military Developments," *Armed Forces Journal International*, March 1986.

[*6*] Fackler, M. L., "Ballistics Injury," *Annals of Emergency Medicine*, Vol. 15, No. 12, Dec. 1986, pp. 110-114.

[*7*] Lewis, R. H., Clark, M. A., and O'Connell, K. J., "Preparation of Gelatin Blocks Containing Tissue Samples for Use in Ballistics Research," *American Journal of Forensic Medical Pathology*, Vol. 3, No. 2, 1982, pp. 181-184.

[*8*] Charters, A. C., III and Charters, A. C., "Wounding Mechanisms of Very High Velocity Projectiles," *Journal of Trauma*, Vol. 16, 1976, pp. 464-470.

[*9*] Berlin, R., Gelin, L. E., Janzon, B., Lewis, D. H., Rybeck, B., Sandegard, J., and Seeman, T., "Local Effects of Assault Rifle Bullets in Live Tissue," *Acta Chirurgica Scandinavia, Supplement*, Vol. 459, 1976, pp. 2-55.

[*10*] Fackler, M. L. and Malinowski, J. A., "The Wound Profile: A Visual Method of Quantifying Gunshot Wound Components," *Journal of Trauma*, Vol. 25, 1985, pp. 522-529.

[*11*] Orlowski, T., Piecuch, T., Domanieck, J., and Badowsky, A., "Mechanisms of Development of Shot Wounds Caused by Missiles of Different Initial Velocity," *Acta Chirurgica Scandinavia, Supplement*, Vol. 508, 1982, pp. 123-127.

[*12*] Rybeck, B., "Missile Wounding and Hemodynamic Effects of Energy Absorption," *Acta Chirurgica Scandinavica, Supplement*, Vol. 450, 1974, pp. 5-32.

[*13*] Dimond, F. C., Jr. and Rich, N. M., "M-16 Rifle Wounds in Vietnam," *Journal of Trauma*, Vol. 7, 1967, pp. 619-626.

[*14*] *Sierra Bullets Reloading Manual*, Sierra Inc., Santa Fe Springs, CA, 1971.

[*15*] Robens, W. and Kusswetter, W., "Fracture Typing to Human Bone by Assault Missile Trauma," *Acta Chirurgica Scandinavica, Supplement*, Vol. 508, 1981, pp. 223-227.

[*16*] Ragsdale, B. D., "Gunshot Wounds: A Historical Perspective," *Military Medicine*, Vol. 149, No. 6, June 1984, pp. 301-315.

[*17*] Ayoob, M., "Handgun Stopping Power: Part II," *American Handgunner*, Nov./Dec., 1982, pp. 36-37, 52-54, 56.

[18] Bruchey, W. J., Jr. and Frank, D. E., *Handgun Ammunition: Incapacitation Effects*, National Institute of Justice Report 100-83, Law Enforcement Standards Laboratory, National Engineering Laboratory, National Bureau of Standards, Washington, DC, Nov. 1983.

[19] Ragsdale, B. D., Letter to the Editor, *Journal of Forensic Sciences*, Vol. 32, No. 4, July 1987, pp. 838-841.

[20] Kokinakis, W., Neades, D., Piddington, M., and Roecker, E., "A Gelatin Energy Methodology for Estimating Vulnerability of Personnel to Military Rifle System," *Acta Chirurgica Scandinavica, Supplement*, Vol. 489, 1979, pp. 35-55.

[21] Berlin, R., Janzon, B., Rybeck, B., Sandegard, J., and Seeman, T., "Local Effects of Assault Rifle Bullets in Live Tissue," *Acta Chirurgica Scandinavica, Supplement*, Vol. 477, 1977, pp. 5-49.

[22] Fackler, M. L., Surinchak, J. S., Malinowski, J. A., and Bowen, R. E., "Bullet Fragmentation: A Major Cause of Tissue Disruption," *Journal of Trauma*, Vol. 24, 1984, pp. 35-39.

[23] Aebi, F., Bronnimann, E., and Mayor, J., "Some Observations on the Behavior of Small Calibre Projectiles in Soap Targets," *Acta Chirurgica Scandinavica, Supplement*, Vol. 447, 1977, pp. 49-57.

[24] De Veth, C., "Development of the New Second NATO Caliber: The '5.56' with the SS109 Projectile," *Acta Chirurgica Scandinavica, Supplement*, Vol. 508, 1982, pp. 129-134.

[25] Belkin, M., "Wound Ballistics," *Progress in Surgery*, Vol. 16, 1978, pp. 7-24.

[26] Lindsey, D., "The Idolatry of Velocity, or Lies, Damn Lies, and Ballistics," *Journal of Trauma*, Vol. 20, 1980, pp. 1068-1069.

[27] Scott, R., "Pathology of Injuries Caused by High Velocity Missiles," *Clinical Laboratory Medicine*, Vol. 3, 1983, pp. 273-294.

[28] Gawlick, H. and Knappworst, J., *Zielballistische Untersuchungsmethoden an Jagdbuchsengeschossen*, Ballistisches Laboratorium Für Munition der Dynamit, Nobel A G, Werk Stadeln, 1971.

[29] Sellier, K., "Effectiveness of Small Caliber Ammunition," *Acta Chirurgica Scandinavica, Supplement*, Vol. 489, 1979, pp. 13-25.

[30] Huelke, D. F. and Darling, J. H., "Bone Fractures Produced by Bullets," *Journal of Forensic Sciences*, Vol. 9, No. 4, Oct. 1964, pp. 461-469.

Address requests for reprints or additional information to
Bruce D. Ragsdale, M.D.
Sonora Laboratory Sciences/ClinPath Associates, P.C.
1500 S. Dobson Rd., Suite 217
Mesa, AZ 85202