Wounding patterns of military rifle bullets

*by Martin L. Fackler**

Whether we like to admit it or not, the primary purpose of military rifle bullets is to disrupt human tissue. Yet the effects of bullets on bodies – the characteristic tissue disruption patterns produced by various bullets – remains unclear even to many of those who design and produce bullets. Surgeons who are called upon to treat the damage bullets cause, with few exceptions, lack practical knowledge of bullet effects. Attempts to fill this information void with formulae, graphs, flawed experiments, invalid assumptions, and theories based on half-truth (or no truth at all) have only increased confusion.[1,2]

The obvious – simply measuring, recording and describing the disruption produced by various calibres and bullet types – has largely been ignored in favour of more dramatic and complex methodology. To illustrate the problem: if a neighbour told you that a meteorite had fallen into his back yard, wouldn't you ask him how deep and how large a hole it had made? If he replied that he had, on good authority, an estimation of the meteor's striking velocity and the amount of kinetic energy it had "deposited" and gave you both these figures, you might be impressed by the sophistication of this information, but you still wouldn't know how big a hole he had in his yard.

Roger Frost, in his cogent editorial "Bullet holes in theories" (*IDR* 8/1988 p.875) suggested that the various groups interested in gunshot wounds neet to "start talking to one another". Let's add that the talk needs to be in terms that can be understood by all – to *inform* rather than to impress.

In order to illustrate the penetrating projectile-body tissue interaction, the "wound profile" method was developed. It is an attempt to present a useful approximation of the pertinent, useful, factual data to clarify bullet effects in a form that can be readily understood.[3] The profiles depict the maximum disruption that a given bullet can be expected to produce in the elastic soft tissue of the living animal. The "permanent cavity" indicated on the wound profiles is the "bullet hole" produced by the projectile *crushing* the tissue it strikes. The "temporary cavity" shows the approximate extent to which the walls of this hole were *stretched* a few milliseconds after bullet passage (entirely analogous to a splash in water).

Anyone who has ever seen a bullet hole recognises that in many cases it is, in fact, more what might be called a potential hole; it need not be gaping open. One can, however, easily pass a probe through it, as is commonly done by forensic pathologists to establish the direction or angle of the shot. How deeply the bullet penetrated

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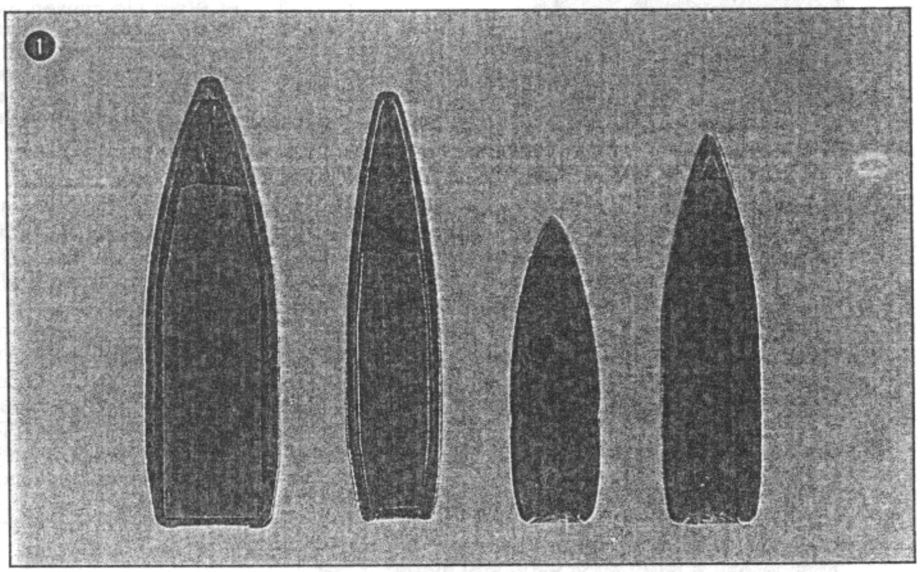
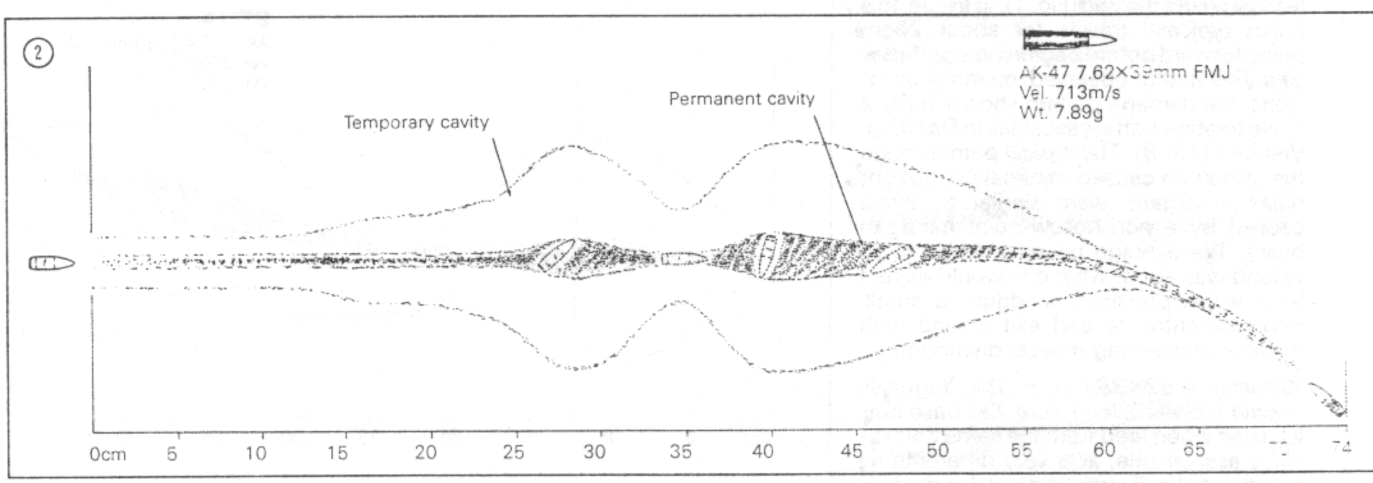


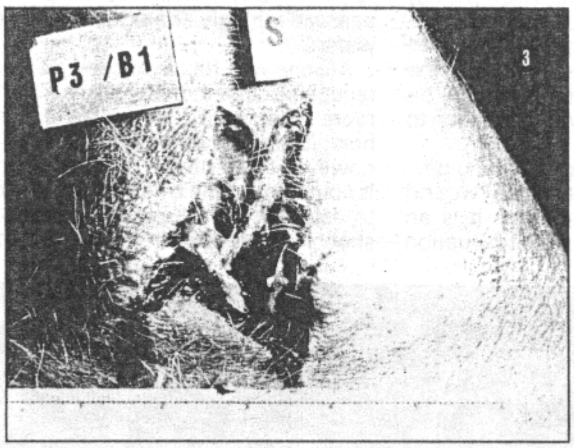
Cross-sections of the bullets fired by (left to right) the AK-47, the AK-74 (note the air space in the tip), the M16A1 (M193 bullet), and the M16A2 (US M855 bullet; the Belgian SS109 bullet has essentially an identical cross-section).



Wound profile of the Soviet AK-47 bullet: The Yugoslav AK-47 bullet begins significant yaw after only about 9cm of tissue penetration (blotting out the first 17cm of the profile as shown leaves a close approximation of the Yugoslav bullet's behaviour).

and its attitude (yawed or straight) and form (deformed or fragmented) as it penetrated, along with the approximate distance the walls of the hole were stretched after the bullet passed (temporary cavity) – this is the crucial information needed to understand the wounding mechanisms.

To describe wounding patterns of the common military rifle bullets in use today, wound profiles will be used along with a description of the two characteristic wounds for each bullet. A simple abdominal wound, and an uncomplicated (didn't hit bone or large vessels) human thigh wound caused by each bullet will be described to demonstrate how the material presented as wound profiles can be put to practical use. This should give the combat surgeon some idea of what to expect. His descriptions of the wounds he actually treats, if they differ significantly from the expected pattern, might be the first indication of a change in enemy weapon or bullet type. Patterns of bullet fragmentation as seen on x-ray, or even the tissue disruption pattern as observed in the body, can be compared with the series of wound profiles to estimate the bullet type when the bullet has passed entirely through.



Stellate exit wound in thigh of 90kg pig caused by the skin's being stretched beyond its breaking point by a 14cm temporary cavity. The path of the AK-74's bullet took it only through soft tissue.

Current rifle bullets

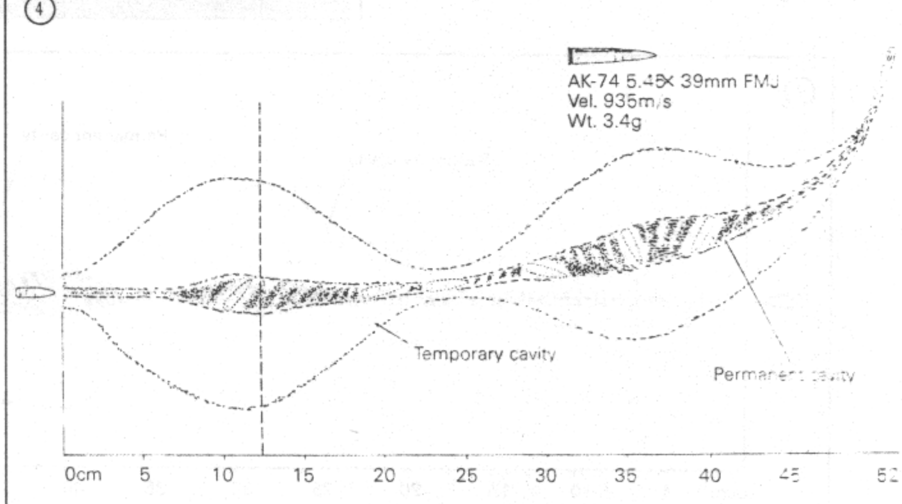
Soviet 7.62×39mm – The Soviet AK-47 Kalashnikov fires a full-metal-jacketed, boat-tail bullet that has a copper-plated steel jacket, a large steel core, and some lead between the two (Fig. 1). In tissue, this bullet typically travels for about 26cm point-forward before beginning significant yaw. This author observed, on many occasions, the damage pattern shown in Fig 2 while treating battle casualties in Da Nang, Vietnam (1968). The typical path through the abdomen caused minimal disruption; holes in organs were similar to those caused by a non-hollow-point handgun bullet. The average uncomplicated thigh wound was about what one would expect from a low-powered handgun: a small, punctate entrance and exit wound with minimal intervening muscle disruption.

Yugoslav 7.62×39mm – The Yugoslav copper-jacketed, lead-core, flat-base bullet, even when fired from the same Kalashnikov assault rifle, acts very differently in tissue. It typically travels point-forward for only about 9cm before yawing. Due to the lead core, this bullet flattens somewhat as it yaws, squeezing a few small lead fragments out at its open base, but this does not add significantly to its wounding potential. Referring to the wound profile of the Soviet AK-47 bullet (Fig. 2) and blotting out the first 17cm of the projectile path will leave a good approximation of what one might expect from this bullet.

Since this bullet would be travelling sideways through most of its path in an abdominal wound, it would be expected to cut a swath over three times the dimension made by the bullet travelling point forward. In addition to the larger hole in organs from the sideways-travelling bullet, the tissue surrounding the bullet path will be stretched considerably from temporary cavitation. Actual damage from the stretch of cavitation can vary from an almost explosive effect, widely splitting a solid organ such as the liver, or a hollow one such as the bladder *if it is full at the time it is hit*, to almost no observable effect if the hollow organs (such as intestines) when hit contain little liquid and/or air. The exit wound may be punctate or oblong, depending on the bullet's orientation as it struck the abdominal wall at the exit point. The exit wound could be stellate if sufficient wounding potential remains at this point on the bullet path. The thigh entrance wound will be small and punctate but the exit wound will probably be stellate, measuring up to 11cm from the tips of opposing splits, as shown in Fig. 3. The stellate exit wound results from the temporary cavity simply stretching the skin beyond its breaking point. These stellate wounds generally bleed very little. Small-to medium-sized vessels are certainly cut or torn, but the temporary cavity tearing action generally stimulates the tiny muscles in the vessel walls to constrict and clots will form in their open ends, limiting blood loss. Being wide open, these wounds tend to drain and heal amazingly well even in situations of limited surgical resources. [4,5]This increased tissue disruption of the leg will, of course, temporarily limit the mobility of the person hit to a greater extent than wounds causing less tissue disruption.

Soviet 5.45×39mm – This is fired from the AK-74, which is the Soviet contribution to the new generation of smaller-calibre assault rifles and which produces the wound profile seen in Fig. 4. The full-metal-jacketed bullet designed for this weapon has a copper-plated steel jacket and a largely steel core, as does the bullet of its predecessor, the AK-47. A unique design feature of the AK-74, however, is an air-space (about 5mm long) inside the jacket at the bullet's tip (Fig 1). The speculation that this air-space would cause bullet deformation and fragmentation on impact proved to be unfounded, but the air-space does serve to shift the bullet's centre of mass toward the rear, possibly contributing to its very early yaw. In addition, on bullet impact with tissue, the lead just behind the air-space shifts forward into this space. This shift of lead occurs asymmetrically (Fig 5) and may be one reason for the peculiar curvature of this bul-

The vertical line on this wound profile of the AK-74 bullet indicates the location of the exit wound shown in Fig. 3.



let's path in the last half of its path through tissue (Fig 4). Only in a shot with a long tissue path, like an oblique shot through the torso, would this curved path be evident; it doesn't really add anything to wounding capacity, but might cause an occasional confusing path through tissue. This bullet yaws after only about 7cm of tissue penetration, assuring an increased temporary cavity stretch disruption in a higher percentage of extremity hits; other bullets need more tissue depth to yaw and in many cases cause only minimal disruption on extremity hits.

The abdomen and thigh wounds expected from this bullet would be essentially the same as those described above for the Yugoslav variation of the AK-47 bullet.

All pointed bullets that do not deform end their tissue path travelling base first, since this puts their centre of mass forward; this is their stable attitude. The rotation imparted to the bullet by the rifled gun barrel is sufficient to force the bullet to travel point-forward in air (in properly designed weapons), but not in tissue where such factors as bullet shape and the location of centre of mass far outweigh rotation effects. The bi-lobed yaw patterns shown in the profiles of the AK-47 and the AK-74 represent what is seen in most shots. Sometimes the bullet yaws to 180°, or the base-forward position, in one cycle. These variations, along with the curvature in bullet path at or near the end of tissue path, are of far less importance than the distance the bullet travels point-forward before significant yaw begins.

US M193 5.56×45mm – This bullet is fired from the US armed forces' first-generation smaller-calibre rifle, the M16A1. The large permanent cavity it produces, shown in the wound profile (Fig. 6), was observed by surgeons who served in Vietnam, but the tissue disruption mechanism responsible was not clear until the importance of bullet fragmentation as a cause of tissue disruption was worked out and described.[6] As shown on the wound profile, this full-metal-jacketed bullet travels point-forward in tissue for about 12cm, after which it yaws to 90°, flattens, and breaks at the cannelure (groove around bullet midsection into which the cartridge neck is crimped). The bullet point flattens but remains in one piece, retaining about 60 per cent of the original bullet weight. The rear portion breaks into many fragments that penetrate up to 7cm radially from the bullet path. The temporary cavity stretch, its effect increased by perforation and weakening of the tissue by fragments, then causes a much enlarged *permanent cavity* by detaching tissue pieces. The degree of bullet fragmentation decreases with increased shooting distance (as striking velocity decreases), as shown in Fig. 7. At a shooting distance over about 100m the bullet breaks at the cannelure, forming two large fragments and, at over 200m, it no longer breaks, although it continues to flatten somewhat, until 400m. This consistent change in deformation/fragmentation pattern has an important forensic application. It can be used to estimate shooting distance if the bullet is recovered in the body and has penetrated only soft tissue.

The effects of this bullet in the abdomen shot will show the temporary cavity effects as described for the Yugoslav AK-47 and, in addition, there will be an increased tissue disruption from the synergistic effect of temporary cavitation acting on tissue that has been weakened by bullet fragmentation. Instead of finding a hole consistent with the size of the bullet in hollow organs such as the intestine, we typically find a hole left by missing tissue of up to 7cm in diameter (see permanent cavity in Fig. 6). The thigh entrance wound will be small and punctate. The first part of the tissue path will show minimal disruption. The exit will vary from the small punctate hole described for the Soviet AK-47 to the stellate exit described for the Yugoslav AK-47, depending on how thick the thigh is where the bullet perforates it. In a sufficiently thick thigh, the M193 bullet fragmentation is also likely to cause a significant loss of tissue and possibly one or more small exit wounds near the large stellate one.

NATO M855/SS109 5.6×45mm – The slightly heavier and longer American M855 bullet shot from the M16A2 assault rifle is replacing the M193 bullet shot from the M16A1 as the standard bullet of the US armed forces. FN Herstal originally developed this bullet type (which has a steel "penetrator" as the forward part of its core – Fig. 1) designating its bullet the SS109. The wound profile (Fig. 8) is very similar to that produced by the M193 bullet. Although the SS109 and the M855 are *not* the same bullet, their differences are small and one almost needs a magnifying glass and a side-by-side comparison to differentiate the two. There is little difference in their performance in tissue.

The abdominal and the thigh wound produced by the M855 or the SS109 bullets would be essentially the same as those described above for the M16A1 M193 bullet.

The longer 5.56mm bullets (M855, SS109) need a higher rotational velocity to maintain stabilisation in air. FN claimed that this faster rotation also causes the

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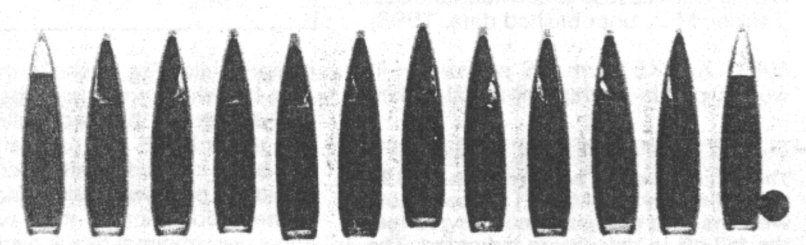

X-ray of the recovered bullets from ten consecutive shots with the AK-74 into ordnance gelatin: One unfired AK-74 bullet is shown on each side for comparison. Note the forward shift of lead in the core, which in every case was asymmetric.

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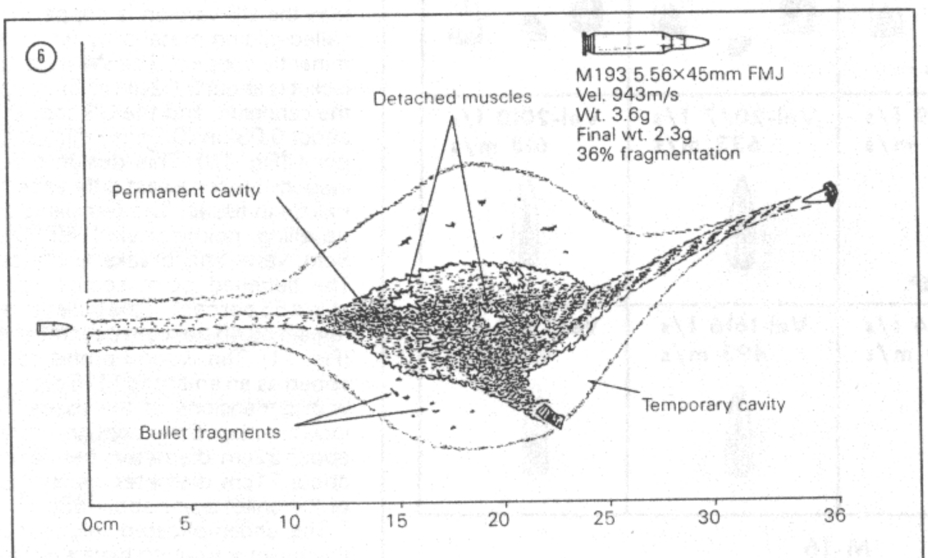
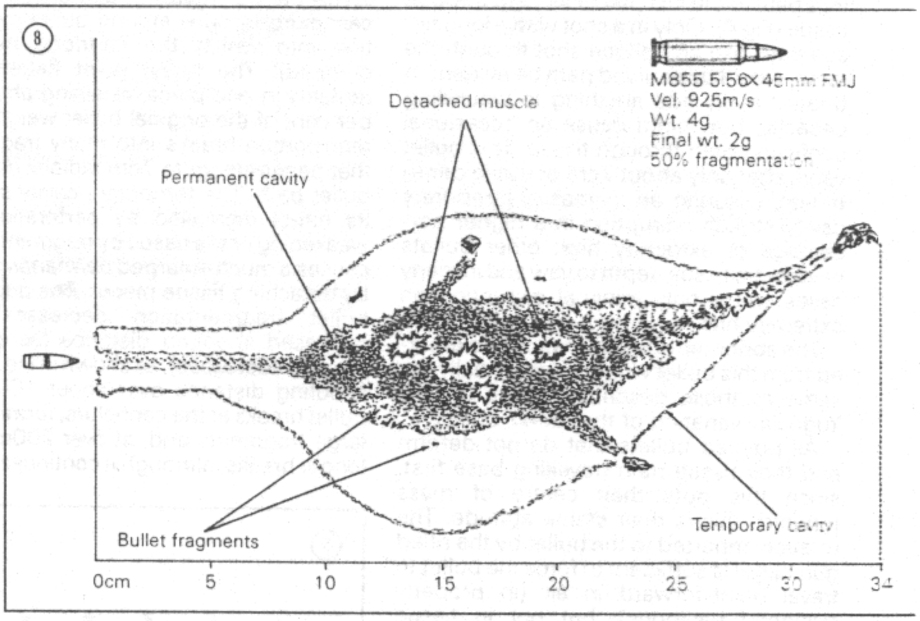


Wound profile of the M193 (M16A1) bullet: Fragmenting rifle bullets regularly detach pieces of tissue, thereby causing a larger permanent cavity.

SS109 to have a significantly longer path in tissue before marked yaw occurs, thus producing wounds of less severity. This is simply untrue (compare Fig. 6 with Fig. 8). Additional rotation beyond that needed to keep the bullet straight in air appears to have little or no effect on the projectile's behaviour in tissue. However, there is a situation concerning rotation rates whereby these longer 5.56mm bullets can cause *increased* wound severity. Shooting the SS109 or M855 bullet in the older M16A1 rifle barrel *(they are not intended for use in this 1-in-12in twist barrel, but in the newer M16A2's 1-in-7in twist)* produces a bullet spin rate *insufficient to stabilise the longer bullets.* Such a bullet will yaw up to 70° in its path through air. Striking at this high yaw angle (essentially travelling sideways), these bullets break on contact and the marked fragmentation, acting in synergy with the temporary cavity stretch, causes a large (over 15cm) stellate wound with the loss of considerable tissue (Fackler, M.L., unpublished data, 1988).



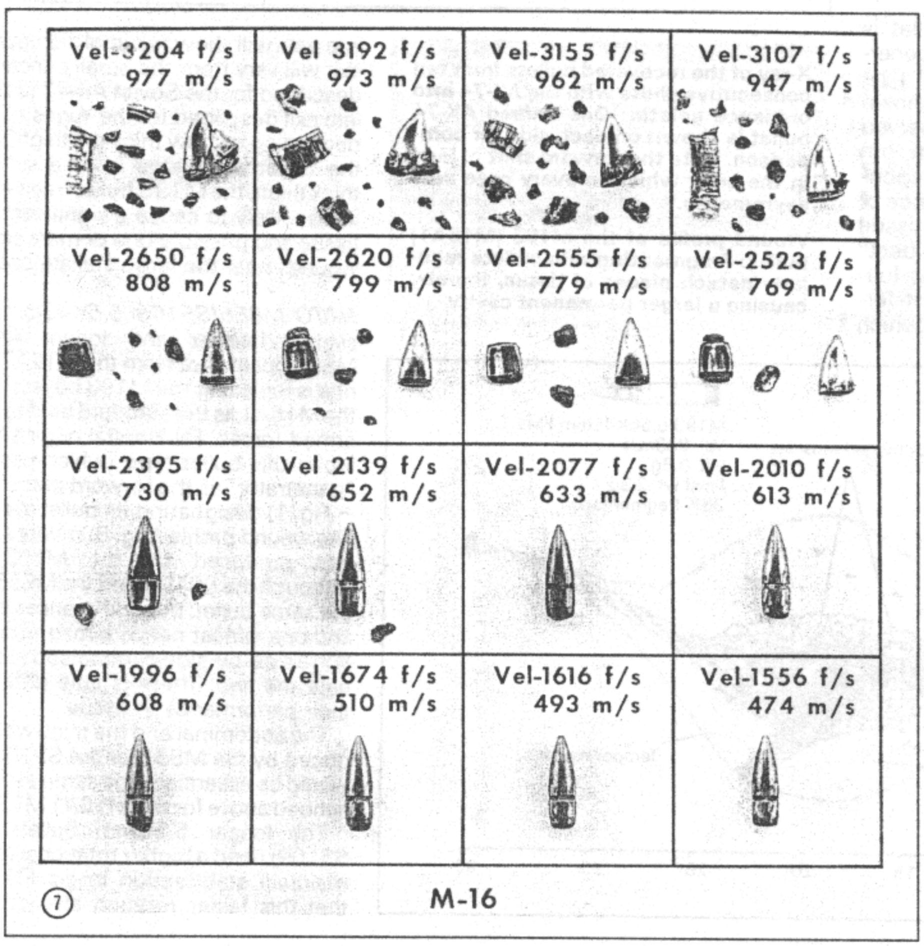
The wound caused by the M855 (or SS109) bullet would be indistinguishable from that caused by the M193 (Fig. 6). Claims of less severe wounding because of the faster bullet spin are unfounded.

NATO 7.62×51mm (US version) – The wound profile of this full-metal-jacketed military bullet (Fig. 9) shows the characteristic behaviour in tissue observed in all non-deforming pointed bullets. It yaws first through 90° and then, after reaching the base-forward position continues the rest of its path with little or no yaw.

The uncomplicated thigh wound might show very minimal tissue disruption since the streamlined bullet tends to travel point-forward during the first 16cm of its tissue path. The abdominal wound, with a sufficiently long path so that the bullet will yaw causing the large temporary cavity that is seen at depths of 20 to 35cm, would be expected to be very disruptive. If the bullet path is such that this temporary cavity occurs in the liver, this amount of tissue disruption is likely to make survival improbable.

NATO 7.62×51mm (West German version) – The design standards for ammunition that can be called "NATO" ammunition do not specify bullet jacket material or jacket thickness. The construction of the West German 7.62 NATO bullet differs from the US 7.62 NATO round in that the jacket material is copper plated steel, whereas the US version is copper (or the so-called gilding metal alloy, which is predominantly copper). The West German steel jacket is about 0.020in (0.5mm) thick near the cannelure and the US copper jacket is about 0.032in (0.8mm) thick at the same point (Fig. 10). This design difference is responsible for a vast difference in performance in tissue. The German bullet, after travelling point-forward for only about 8cm, yaws and breaks at the cannelure. The flattened point section retains only about 55 per cent of the bullet's weight, the remaining 45 per cent becomes fragments (Fig. 11). The wound profile can be described as an enlarged M16 profile (Fig. 6) with dimensions of the tissue disruption increased by 60 per cent (temporary cavity about 22cm diameter; permanent cavity about 11cm diameter, penetration depth of the bullet point about 58cm).

The uncomplicated thigh wound from this bullet is likely to have a large exit with the loss of substantial tissue near the exit



The fragmentation pattern of the M193 bullet fired by the M16A1: Those shots were made at gradually incrasing range; the fall-off in velocity is indicated. The M193 is unlikely to break up on striking soft tissue at ranges over 200m.

still, this might not be a very serious wound since the bullet fragmentation does not occur until beyond 10cm of penetration depth and, in most shots, the bullet will have passed well beyond the major vessels before this occurs. The abdomen shot, however, because of the much enlarged permanent cavity from bullet fragmentation, is likely to prove fatal in a majority of cases.

Soviet and Chinese 7.62×54mm R (Rimmed case) – This bullet, although not nearly as common as the AK-47 or the others discussed above, is included because it is currently used in the Dragunov sniper rifle and the Communist bloc light machine-guns. Also, since it was the standard Soviet military round in WW1 and WW2 (in the bolt-action Mosin-Nagant), it might well be found in considerable numbers in some Third World countries. The bullet weighs 9.6g; the base is hollowed out with a cone-shaped cavity – 5mm deep for the Soviet, 3mm deep for the Chinese). The Soviet bullet has a copper-plated steel jacket and the Chinese one has a jacket of what appears to be brass. The muzzle velocity is about 853m/s and the wound profile closely resembles that of the 7.62 NATO (US version). Thigh and abdominal shots thus would be as described above for the US 7.62 NATO bullet.

Overview

In addition to the full-metal-jacketed construction which makes them "military" bullets, the pointed ogival "spitzer" tip shape is shared by all modern military bullets. The obvious advantage of this streamlined shape is decreased air drag, allowing the bullet to retain velocity better for improved long-range performance. A modern military 7.62mm bullet (with all-lead core) will lose only about one-third of its muzzle velocity over 500 yards (457m); the same weight bullet with a round-nose shape loses more than one-half of its velocity over the same distance.

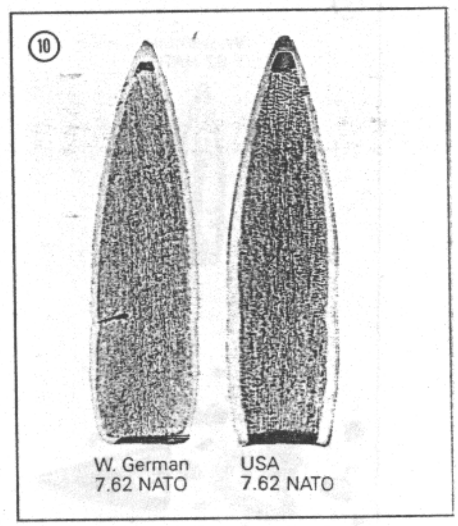
More pertinent to the present discussion is this pointed shape's effect on the bullet's yaw in tissue. The first full-metal-jacketed bullets (1885-1910) were over four calibres long and round-nosed. Typical of this bullet type are the 6.5mm Carcano and the 30-40 Krag bullets; they penetrate tissue simulant travelling point-forward for 50cm or more before significant yaw begins (Fackler, M.L., unpublished data, 1987). The very minimal wounding effect produced by these early round-nosed jacketed bullets was remarked upon by surgeons of the time (Kocher, Markins, Brunner, Abbott, LaGarde, etc.). Even those soldiers with through-and-through chest wounds in which the bullet missed the large vessels (but passed through the lung) would be fit to rejoin their units in a few weeks[7].

The distance that the military-type bullet travels point-forward before yawing is critical to wounding effects. The distance shown on the wound profiles is the average distance at which this occurs. However, it is important to recognise how much shot-to-shot variation from this average distance can be expected. Taking the M16 wound profile (Fig 6) as an example, it shows significant yaw starting at a 12cm penetration depth. Seven out of ten shots can be expected to begin yaw within 25 per cent of this distance (between nine and 15cm penetration depth). This plus or minus 25 per cent rule is a useful approximation that can be applied to the other wound profiles. Let us apply it to the 50cm distance-to-yaw for the older bullets; whether the bullet begins to yaw between 37 or 63cm penetration distance does not effect most wounds of the human body because, in the great majority of cases, the total tissue path will be less than 37cm.

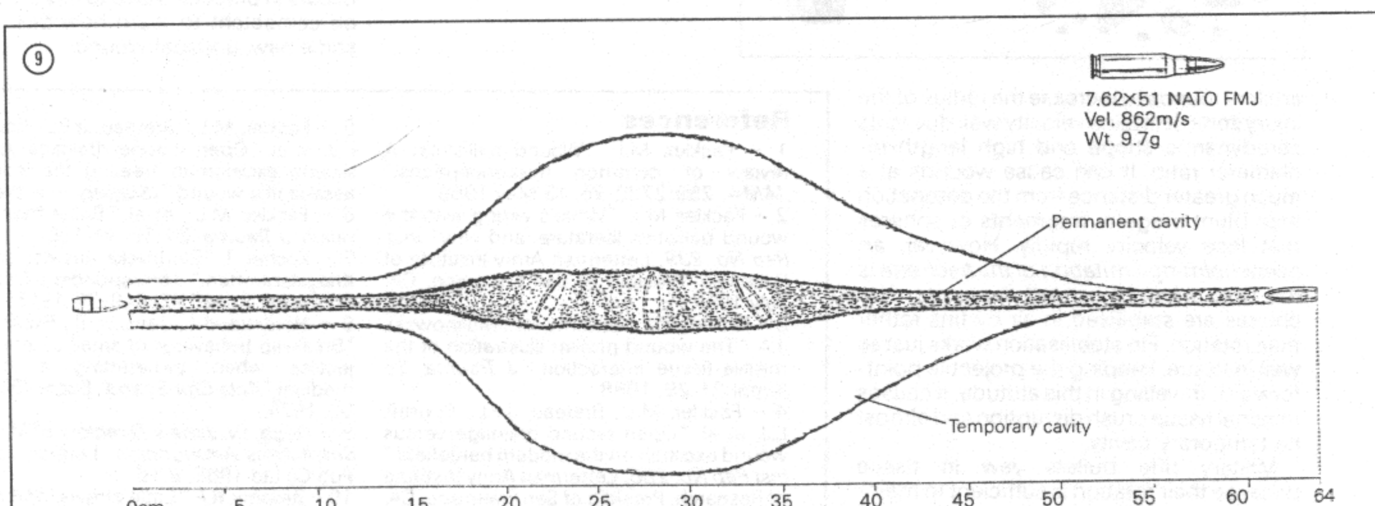
Conversely, inconsistent effects have been noted in wounds caused by the M16 and other modern military bullets. Considering the variation in length of the possible tissue path through the human body, this "inconsistency" of effect is to be expected. Beware! This variation can be used to dupe the unsuspecting. A series of shots through a 14 or 15cm block of tissue simulant or the leg of a 25kg animal can give enough variation so that, by selective choice of exit wound photographs, one can "prove" any point one wishes (such as one bullet being less "humane" than another). The author hopes that understanding this will make the reader less likely prey to this sort of deception.

Bullet mass and bullet striking velocity establish a bullet's potential; they set the limit on the tissue disruption it can produce. Bullet shape and construction determine how much of this potential is actually used to disrupt tissue; they are the major determinants of bullet effect. Far and away the most disruptive bullet of those described is the West German 7.62 NATO round. Its fragmenting behavior maximises utilisation of its much higher potential (bullet mass well over twice that of any of the 5.56mm bullets and velocity only about ten percent less than theirs) for tissue disruption.

Cross-sections comparing the construction of the West German and US 7.62mm NATO bullets: The jacket of the American bullet is more than 50 per cent thicker than that of the German one.



Wound profile of the 7.62mm NATO (US version): This bullet does not ordinarily deform on striking soft tissue at any range.



This author has not tested other European 7.62 NATO rounds, but the "NATO standards" apparently allow bullet designers great latitude in the choice of bullet jacket material and thickness. In 1979 a published high-speed x-ray photograph showed the Swedish 7.62 equivalent to the 7.62 NATO bullet breaking in a soap block shot at a range of 100m.[8] Although bullet fragments were not recovered and photographed (the importance of bullet fragmentation in tissue disruption was not well recognised at the time), one must suspect the same very disruptive behaviour from this bullet as from the West German round. This is particularly ironic since the Swedish wound ballistics program was using every means possible to discredit the M16 as "inhumane" while, at the same time, Sweden was producing a 7.62 military bullet that caused far more extensive wounds than the M16.

Future combat rifle considerations

Two concepts that are being considered deserve comment. First, the flechette (a nail with fins) used as a single small-arm projectile: this projectile has been used in artillery rounds to increase the radius of the injury zone. It retains velocity well due to its aerodynamic shape and high length-to-diameter ratio. It can cause wounds at a much greater distance from the detonation than blunt irregular fragments or spheres that lose velocity rapidly. However, *an overwhelming limitation of the flechette is the very minimal wound it causes*. Flechettes are stabilised in air by fins rather than rotation. Fin stabilisation works just as well in tissue, keeping the projectile point-forward. Travelling in this attitude, it causes minimal tissue crush disruption and almost no temporary cavity.

Military rifle bullets yaw in tissue because their rotation is sufficient to maintain their point-forward travel in air, but insufficient to maintain that position in tissue – sooner or later they yaw to reach their stable centre-of-mass-forward attitude. Flechettes have the drag of the fins permanently attached on their tail to keep the point forward; this stabilises them in air *and in tissue*.

Considerable confusion exists concerning the effects of flechettes. In a recent publication one finds the erroneous statement "...the flechette can inflict severe wounds by virtue of its poor stabilisation and readiness to tumble on impact...".[9] Bellamy's "Little arrows",[10] the classic paper on flechettes, points out a reason for the misconceptions: Many flechettes launched from artillery shells are bent by the force of the detonation. Persons close to the detonation are penetrated by these bent flechettes. It has been assumed that the bending resulted from the flechettes striking the body. Bellamy's report is in accord with this author's personal experience treating flechette wounds on the battlefield – flechettes, as used thus far in warfare, travel straight in tissue and cause very minimal tissue disruption.

The second consideration is the use of the three-round burst at a rate of fire of 2,000 r/min in the Heckler & Koch G11 caseless ammunition rifle. This burst fire and high cyclic rate are designed to increase hit probability. This may be a significant factor in the weapon's effectiveness at ranges over 200m, where only one of the three rounds is likely to hit. What, however, will be the wounding effect of this three-round burst at ranges under 50m where most of the casualties have occurred in recent conflicts? At this range the three rounds will hit the body within a few centimetres of one another; each successive round will hit within 30 milliseconds of the previous one. The first temporary cavitation pulsation (expansion and collapse) might last for 10 to 12 milliseconds; several pulsations of similar duration will follow. The tissue will still be moving from the temporary cavitation caused by the first round when it is subjected to the second temporary cavity, and so on for the third. Will the effect be simply additive, like three separate shots? Or will the close time proximity cause a synergistic effect resulting in a wound that many will call "inhumane"?

This author would like to see some rational testing of effects *(in which the entire projectile-tissue interaction is captured – not just the first 15cm)* as a basis for estimating wounding effects so that the combat surgeon can be forewarned and not, as occurs in practice, have to use the wounded combatant to learn how best to treat some new, unusual wound. ++

Acknowledgements

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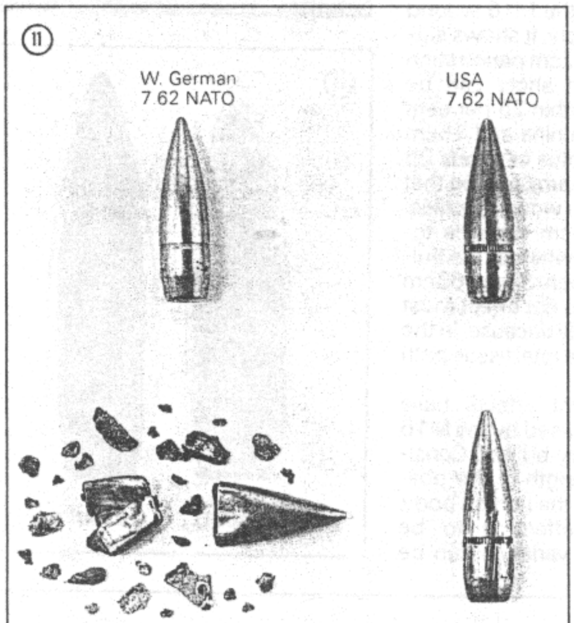

A comparison of 7.62mm NATO bullets before and after firing into ordnance gelatin at a distance of 3m: The fragmentation of the West German version closely resembles the behaviour of the M193 (M16A1) bullet. This breaking up of the West German bullet in shots into ordnance gelatin also occurs at a range of 100m, according to reports in Deutsches Waffenjournal (June 1980).

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