Int J Leg Med (1994) 107: 141–146

ORIGINAL ARTICLE

Peter Juel Thiis Knudsen · Ole Heigaard Sørensen

The initial yaw of some commonly encountered military rifle bullets

Received: 6 May 1994 / Received in revised form: 22 August 1994

Abstract The yaw angle in flight of high velocity bullets has been discussed for a number of years, due to its contribution to the tumbling of the bullet in the target. Since few unclassified reports of contemporary bullets are available, we investigated the yaw angles of the bullets used in the M16A2, G3, AK-47 and AK-74 rifles by the shadowgraph technique. Our results show that bullets from military rifles tend to stabilize at less than 3° within 25 m, and this angle has been thought to be insignificant in the production of gunshot wounds. Bullets from some modern small calibre high velocity rifles such as the M16A2 and the AK-74 can have quite large yaw angles in their initial flight. The results, which confirm the opinion of contemporary writers, should settle the controversy in this area of wound ballistics.

Key words Ballistics · Wound ballistics · Yaw

Zusammenfassung Die Anstellwinkel von Hochgeschwindigkeitsgeschossen werden wegen ihres Einflusses auf das Taumeln des Geschosses im Ziel seit langem diskutiert. Da hierzu nur wenige unklassifizierte Berichte veröffentlicht worden sind, haben wir die Anstellwinkel von Geschossen aus den Gewehren M16A2, G3, AK-47 und AK-74 mit der Shadowgraphtechnik untersucht. Unsere Ergebnisse zeigen, daß sich die Anstellwinkel von Geschossen aus Militärgewehren nach 25 m bei weniger als 3° stabilisieren. Diese Winkel werden allgemein als bedeutungslos eingeschätzt. Die Projektile einiger moderner Hochgeschwindigkeitsgewehre wie M16A2 und AK-74 können im ersten Teil der Flugbahn relativ große Anstellwinkel erreichen. Unsere Resultate bestätigen die Meinung zeitgenössischer Autoren und sollten dazu beitragen, die Kontroversen auf diesem Gebiet der Wundballistik aufzulösen.

Schlüsselwörter Ballistik · Wundballistik · Yaw

P. J. T. Knudsen (✉)
Institute of Pathology, Aarhus University Hospital, Kommunehospitalet, DK-8000 Århus C, Denmark

O. H. Sørensen
TERMA Elektronik AS, DK-8250 Lystrup, Denmark

Introduction

Many factors are of importance in wounds caused by military rifle ammunition, one of them being the angular movement, if any, of the bullet after hitting the target (Janzon et al. 1979; Janzon 1983). It is universally agreed that the "yawing" of the bullet contributes significantly to its wounding power, especially as it may lead to its breaking up (Fackler et al. 1984a; Moffat 1984). It is also accepted, that a bullet will tumble earlier on its way through tissue, if it is already yawing when it hits the target, than will one whose axis is parallel to the line of flight on impact (Sellier and Kneubuehl 1994b). The immediate pre-impact yaw angle has been hotly debated in the wound ballistics literature (Fackler 1987, 1988). Despite the fact that the necessary technology has been available for more than a century (Boys 1890, 1893a, b), surprisingly few papers that have properly documented the yaw angle have been published. Statements about the yaw angle of bullets have been anecdotal, classified (DiMaio 1985; Kneubuehl and Maissen 1978) or misleading (Fackler 1987, 1988). We therefore decided to investigate the yaw angles of bullets from a number of well known military rifles, using the shadowgraph technique.

The M16A2 is the best known weapon of the new generation of small calibre high velocity military rifles in the West. The NATO countries and a number of neutral countries have chosen the calibre 5.56 mm × 45 to replace calibre 7.62 mm NATO. The M16 and M16A1, produced by Colt Industries Inc., won fame and notoriety during the Viet Nam war and a large amount of literature is available on this subject. The M16 was strongly critizised, however, an attempt to outlaw it in the UN was rejected (Sellier and Kneubuehl 1994a). The M16 and M16A1 used the M193 bullet, but by later modification to the M16A2 the heavier M855 bullet with a slightly lower muzzle velocity was adopted, and this bullet, manufactured by FN (Belgium), designated SS109 is the NATO standard (Berlin et al. 1976; DeVeth 1982; Fackler 1989; Nordstrand et al. 1979). It has been claimed that it is less harmful than the M193, but this has not been confirmed by independent observers (Berlin et al. 1988; Fackler 1989). The G3 infantry rifle is manufactured by Heckler & Koch (Germany), and was adopted by the Bundeswehr in the beginning of the 1960s and later by, among others, Denmark (M75) and license produced in many countries. The G3 uses the 7.62 mm × 51 cartridge, in NATO standard and this cartridge is generally called the 7.62 mm NATO. The 7.62 mm NATO ammunition has been investigated with a view to fragmentation (Fackler 1989; Knudsen and Theilade 1993). The AK47 is probably the best known example of the so-called assault rifle. The robust and simple design will allow maltreatment and still remain serviceable. The AK-47 and its slightly modified successor the AKM is used by the ex-Warsaw Pact countries and China and is made on license all over the world in different versions. The AK-47 uses calibre 7.62 mm × 39 cartridges and some designs of the bullet may have a steel penetrator (Fackler 1989). The bullet is to a large extent non-deforming or non-fragmenting (Aebi et al. 1977; Fackler 1989; Fackler et al. 1990; Nordstrand et al. 1979; Ryan et al. 1988). The AK-74 in calibre 5.45 mm × 39 is the late Warsaw Pact answer to the M-16 and represents the most advanced development of the AK-47 which it resembles in design as well as in appearance. The AK-74 bullet is rather similar to the SS109, having a steel penetrator extending for most of the length of the bullet and fragmentation is not seen except when penetrating hard targets. The behaviour of the bullet in tissue simulants is now ascribed to the shape of the bullet and not due to a change in center of gravity caused by the cavity in its tip (Bowen and Bellamy 1988; Fackler et al. 1984b; Fackler and Malinowski 1988; Fackler 1989, 1991).

Fig. 1 The setup using 2 Shadowgraph Stations BS-520

Material and methods

For the investigation 4 types of military rifles in current use were selected. The M16A2 used was in as-new condition, no. 8181826, with in-bore measurement of 5.55 mm at the breach and 5.54 mm at the middle of the barrel and at the muzzle. Dispersion ("worst" group of 7–9 shots) at 42 m was within a circle of 9 cm diameter. Ammunition used was Swedish, made by FFV, conforming to NATO standard, 5.56 mm sk ptr 5 stkprj, Lot no. 07086012 08-28. The average muzzle velocity was 935 m/sec and the bullet weight was 4.00 g. The G3 used was manufactured in 1964, no. G3HK 0324484 1/84, with in-bore measurements of 7.62 mm at the breach, at the middle of the barrel and at the muzzle, and dispersion ("worst" group of 7–10 shots) at 42 m was within a circle of 11.5 cm diameter. Since the results were not as good as we had expected, another weapon with the same specifications was tried, but this gave essentially the same results. Ammunition used was Danish, made by AMA, 7.62 mm SKPT M/75, Lot no. 02AMA91. The average muzzle velocity was 810 m/sec and the bullet weight was 9.42 g. The AK-47 used was license-manufactured in DDR in 1962, no. 62 J 2657, with in-bore measurements of 7.61 mm at the breach and 7.62 mm at the middle of the barrel and at the muzzle. Dispersion at 42 m ("worst" group of 8–9 shots) was within a circle of 8.5 cm diameter. The ammunition was Finnish, made by Lapua, 7.62 × 39 Luoti S405, Lot no. JIKW. The average muzzle velocity was 720 m/sec and the bullet weight was 7.98 g. The AK-74 used was license-manufactured in the People's Republic of China in 1980, no. 117496, with in-bore measurements of 5.46 mm at the

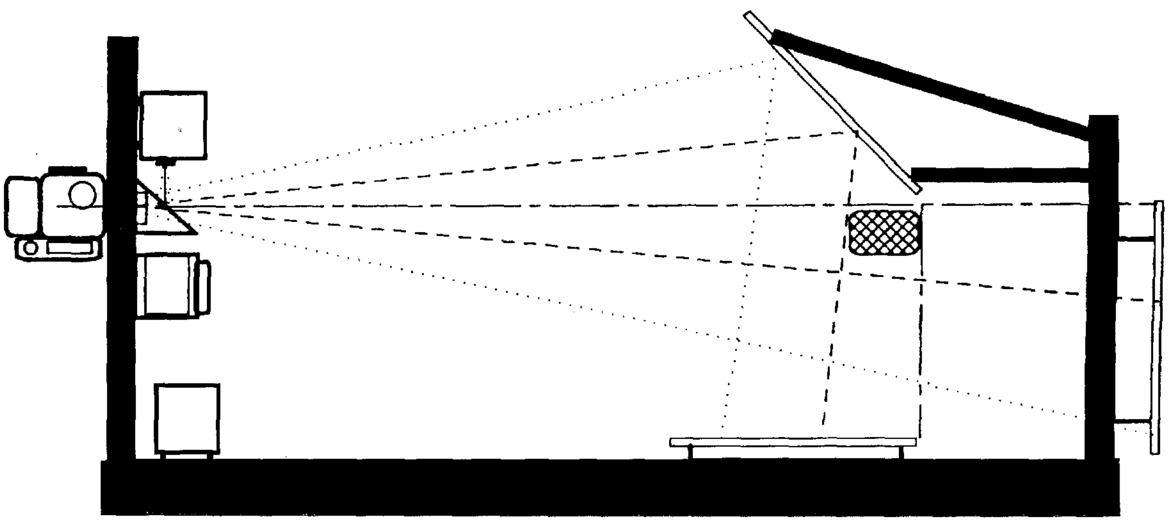

Fig. 2 Graphic presentation of the Shadowgraph Station BS-520

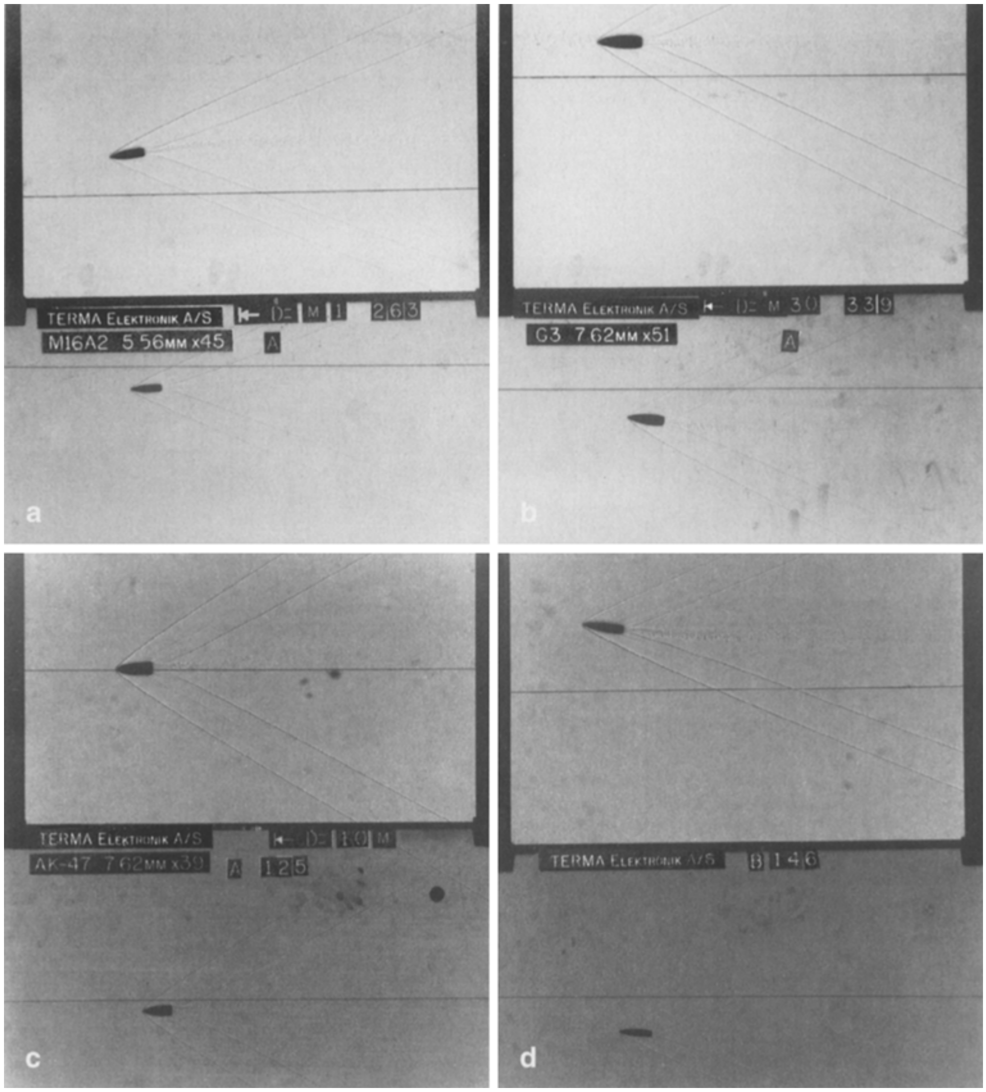

Fig. 3 Photographs of bullets with high angles of yaw from **a** the M16A2 8.00°, **b** the G3 6.38°, **c** the AK-47 2.87°, **d** the AK-74 9.72°

breach, at the middle of the barrel and at the muzzle. Dispersion at 42 m ("worst" group of 8 shots) was within a circle of 8 cm diameter. The ammunition was produced in the GDR, lot no. 080. The average muzzle velocity was 910 m/sec and the bullet weight was 3.44 g.

In order to demonstrate the angle of the bullet in relation to the trajectory, it had to be photographed in 2 planes at 90° angles. The technology for taking photographs for this purpose has been known for a number of years and for this investigation equipment produced by TERMA Elektronik AS was used. This was a duplicated system consisting of 2 Shadowgraph Stations BS-520, each consisting of a system of mirrors and a Hasselblad 553 camera fitted with a Zeiss 150 mm lens, AI-500 sparkflash, EO-130 infrared screen and AP-500 power supply (Figs. 1 and 2). The films used were Kodak Tri-x and TMY 6053, both 400 ASA, f = 11. The system was adjusted using a Kevlar wire through the barrel to establish the trajectory and 2 reference wires, which would give a perfect base for measurement on both the 2 renderings of the bullet at 90° angles. The rigidly mounted rifle was fired in the darkened shooting tunnel by remote control. The bullet triggered the sparkflash by way of an infrared screen with the camera lens focused at the shadow of the passing bullet. In order to record the velocity a Doppler radar equipment was used (Knudsen and Svender 1994). This radar equipment, viewing the bullet from behind, gave information of the velocity and might be used to determine yaw in addition to the velocity information. A DR5000 Velocity Analyzer linked to a 94 Ghz IM400 Doppler radar antenna unit manufactured by TERMA Elektronik AS was used.

The experiments were carried out in a shooting tunnel 50 m long, which meant that a range of a little over 40 m was available for the tests. The experiments were conducted at 20°C. While the ideal set-up would be an infinite number of cameras at infinitely small intervals along the whole of the trajectory, reasons of space and economy dictated a considerably less ambitious system. In order to obtain 2 photos of the same bullet during its trajectory, 2 Shadowgraph Stations were used with a distance of 0.7 metres between them. This meant that with predetermined measurement ranges of 1, 5, 10, 20, 30 and 40 metres measurements were obtained at 1, 1.7, 5, 5.7, 10, 10.7 up to 40.7 metres. The photos were developed to A4 size, providing a good base for measuring deviations of the flight angle of the bullet from the shadow of the reference wire to an accuracy of approximately 0.3–0.4° (Fig. 3 a–d). For each of the 4 weapons at least 5 shots were fired at the various ranges giving a minimum of 60 measurements for each weapon.

Results

The results of the measurements of yaw angle are given in Table 1. An average for each range was computed, and this

Table 1 Yaw angles, average and min-max values in degrees of bullets fired from the weapons examined

Range	M16A2	G3	AK-47	AK-74
1 m	4.26° (0.91°–8.00°)	3.00° (1.10°–5.00°)	0.73° (0.30°–1.14°)	4.81° (2.55°–6.74°)
1.7 m	0.59° (0.20°–1.39°)	2.64° (1.24°–3.97°)	1.79° (0.72°–2.87°)	5.71° (3.39°–9.72°)
5 m	1.76° (0.89°–2.62°)	2.51° (1.36°–2.72°)	1.16° (0.90°–1.79°)	3.06° (1.04°–5.05°)
5.7 m	1.10° (0.20°–1.36°)	4.18° (3.19°–5.75°)	1.38° (1.00°–1.77°)	2.62° (0.91°–4.00°)
10 m	5.32° (3.62°–6.58°)	3.37° (1.28°–4.59°)	1.63° (0.54°–2.95°)	1.86° (0.60°–3.47°)
10.7 m	2.36° (1.94°–2.70°)	2.44° (1.20°–4.37°)	0.64° (0.10°–0.91°)	2.81° (0.71°–6.84°)
20 m	2.62° (0.76°–4.66°)	2.19° (0.67°–4.56°)	1.09° (0.60°–1.73°)	1.16° (0.32°–2.19°)
20.7 m	1.15° (0.22°–2.12°)	3.67° (2.82°–5.81°)	0.92° (0.42°–2.60°)	3.06° (1.03°–5.89°)
30 m	1.19° (0.22°–2.56°)	4.11° (2.05°–6.38°)	0.89° (0.45°–1.53°)	1.57° (0.30°–2.97°)
30.7 m	2.79° (1.80°–4.03°)	4.62° (2.20°–5.82°)	1.01° (0.28°–1.72°)	1.86° (0.81°–4.01°)
40 m	2.50° (0.57°–3.85°)	3.70° (3.35°–4.14°)	0.47° (0.10°–1.20°)	1.62° (0.45°–2.75°)
40.7 m	0.94° (0.32°–2.02°)	3.06° (2.42°–3.75°)	0.63° (0.00°–1.78°)	2.21° (0.92°–3.40°)

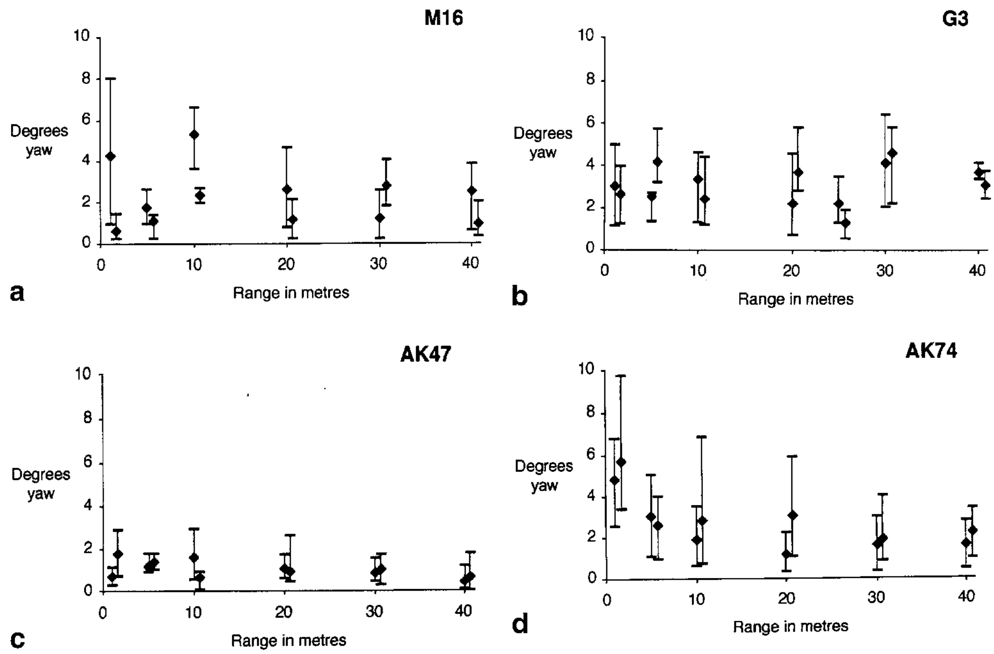

Fig. 4 Yaw angles of bullets from **a** the M16A2, **b** the G3, **c** the AK-47, **d** the AK-74, compared to the distance from the weapon

is given together with the minimum and maximum values. For each weapon the values are illustrated graphically in Fig. 4 a–d. The average value in comparison to the min-max values gives an indication of cases with a wide variation.

The M16A2 has a great variation between range averages in the first 10 m of its trajectory, but after that it seems to be reasonably stable at approx. 2–3° (Fig. 4 a). Only one value at 30 m exceeded 4° by a minuscule margin. The measurements of the G3 showed an average initial yaw of 3° (1°–5°) which was more or less unchanged at 10 m. Even at considerably longer ranges the bullet did not stabilize sufficiently to attain an average yaw angle of less than 3° (Fig. 4b). At 30 m average values are above 4°, and at 40 m maximum values are still close to 4°. The AK-47, the oldest and slowest of the 4 weapons, gave results that were on an average less than 2° at all ranges, and only very few individual bullets exceeded 2° (Fig. 4c), the furthest one at 20.7 m. In comparison, the AK-74, which is a small calibre development of the AK-47, has large yaw-angles in its initial flight, in fact the largest single deviation measured at 9.72° (Fig. 3d), but becomes reasonably stable at longer ranges (Fig. 4d), where it is on par with the M16A2 and better than the G3.

Discussion

The introduction of rifling produced a gyroscopically stabilized bullet. This was of interest to wound ballisticians, since deviation from the ideal behavior of the bullet could have a significant influence on the lesions (Cooper and Ryan 1990). Since even a theoretically ideal bullet, which had been given a gyroscopical stabilization, could not be expected to fly perfectly true, the inevitable tolerances in manufacture of bullets and weapons meant that in addition to this a not inconsiderable lateral or angular movement of the bullet could be expected, especially in the first part of the trajectory (Amato and Rich 1972).

A bullet will lose its stability and start to tumble, when it enters a solid medium such as tissue or tissue simulants.

It is immediately obvious that if the bullet were at an angle to its trajectory as it entered the target, the distance from the entry until the bullet had tumbled 90° or even 180° would be much shorter and the potential for wounding considerably greater, since the "neck" or "narrow channel" would be shorter (Sellier and Kneubuehl 1994b). This part of the trajectory has a length of 15 cm or more in some military rifle bullets, meaning that it may penetrate an arm or a leg before the instability has an effect (Fackler 1986). Some bullets travel a considerably shorter distance in tissue or tissue simulants before tumbling, as is seen in some small caliber weapons such as the M-16 and AK-74 (Bowen and Bellamy 1988). Thus there is a much greater chance that the temporary cavity or the point where the bullet fragments would be within the target. We were surprised when going through the literature to find little evidence of the yaw angles of rifle bullets in flight, and none in the English language literature. This was the more surprising since the technology for photographing the bullets or rather the shadow of the bullets, was pioneered by Prof. Ernst Mach in Prague before the turn of the century (Boys 1890, 1893 a, b). We have no illusions about being the first to show rifle bullets with this technique (Warken 1982), but must by necessity be of the opinion that much of the previous scientific work has been classified, thereby making it inaccessible for civilian scientists and improper to use as a reference (DiMaio 1985; French and Callender 1962; Sellier and Kneubuehl 1994b). So although we realize that some of our experiments have been done before, we found it of interest to present unclassified information about the behavior of the bullets of these 4 well known weapons.

The length of the tunnel and the availability of two Shadowgraph Stations dictated the limitations of the measurements. We chose distances of 1, 5 and 10 metres and then at 10 m intervals up to 40 m, with the second Shadowgraph Station at 0.7 m, in order to get measurements close to the muzzle, where the yaw angles could be expected to be largest. The weapons used were of varying age but since the barrels and the dispersion at 40 m were all within what might be thought to be production tolerances, they are acceptable. It would of course be no problem to increase the yaw angles, either by using worn out barrels or substandard or modified ammunition. Our results indicate that weapons and ammunition were of good quality.

The M16A2 surprised us by having measurements close to the muzzle that would indicate a very stable bullet – apart from the very large yaw angles at 1 m – but further away the yaw angle increased to what we would expect. It ends up being quite stable, as compared to the opinions previously expressed about this weapon (Tikka et al. 1982). Bullets fired from the G3 did not seem to stabilize at short ranges. There are 2 possible explanations for our findings: firstly, that the bullet will not stabilize within the 40 m at our disposal, or that the bullet cannot be stabilized more than we have described. In both cases it will be necessary to investigate the behaviour of the bullet at longer ranges than those accessible to us. Warken (1982) also investigated the G3 using an advanced aeroballistic range and these findings confirm that bullets from the G3 are not very well stabilized at 25 m which corresponds well to our results. Even the absolute angles were not significantly different from ours, which indicates that our technologically more primitive (or limited) investigations were probably representative. The high velocity AK-74 bullet has a considerable initial yaw angle as it leaves the muzzle, but quickly stabilizes at 2–3°, indeed in the later part of its trajectory it is not that different from the M16A2. In contrast the AK-47 is impressively stable at an average yaw angle of at most 2° at all ranges. We thus disagree with the findings by Tikka et al. (1982), who insist that the AK-47 is unstable in flight. We remain unconvinced that measurement of the length of the neck or narrow channel by itself can be used to judge the degree of yaw in air. Variation in yaw angles in flight of less than 1° can hardly be responsible for any great variation in the size of the wound tract.

In conclusion, our experiments tend to confirm the opinion of many authors who, on the basis of undisclosed information, claim that the yaw angles of military rifle bullets of the types investigated tend to stabilize at less than 3° within 25 m. This angle has been thought to be insignificant (French and Callender 1962; Hopkinson and Marshall 1967, Cooper and Ryan 1990), but whether this is true has not been demonstrated convincingly, and this investigation of course does not provide an answer. It would be of interest to combine our methods with gelatin or soap blocks, to discover the effect on the "neck" or "narrow channel" of such small angles. However, small calibre high velocity rifles like the M16A2 and the AK-74 can have quite large yaw angles in their initial flight. Our results should contribute to settling the controversy in this area of wound ballistics.

Acknowledgements The authors want to thank Mr. P. Riis and Ms. J. Johansen, TERMA Elektronik AS, for their assistance. The Army Combat School kindly supplied the weapons and the necessary personnel for the experiment, Major P. S. Nissen, WO1 K. Jensen and LCpl A. Lund handling the administrative and weapon-related chores. Graphical presentation of the yaw angles were kindly produced by Dr. Niels Korsgaard and photos by Ms. A. Dalmose and Mr. S. Shapiro, of the Institute of Pathology. The opinions expressed herein are those of the authors and should not be construed as the opinion of the Ministry of Defence.

References

Aebi F, Brönnimann E, Mayor J (1977) Some observations on the behaviour of small calibre projectiles in soap targets. Acta Chir Scand [Suppl] 477:49–57

Amato JJ, Rich NM (1972) Temporary cavity effects in blood vessel injury by high-velocity missiles. J Cardiovasc Surg 13:147–155

Berlin R, Gelin LE, Janzon B, Lewis DH, Rybeck B, Sandegård J, Seeman T (1976) Local effects of assault rifle bullets in live tissues. Acta Chir Scand [Suppl] 459:1–76

Berlin R, Janzon B, Lidén E, Nordström G, Schantz B, Seeman T, Westling F (1988) Wound ballistics of Swedish 5.56-mm assault rifle AK5. J Trauma [Suppl] 28:75–83

Bowen TE, Bellamy RF (eds) (1988) Emergency War Surgery 2nd edn. United States Government Printing Office, Washington DC, pp 13–34

Boys CV (1890) The velocities of projectiles. Nature 42:250–251
Boys CV (1893a) On electric spark photographs; or photography of flying bullets etc, by the light of the electric spark I. Nature 47:415–421
Boys CV (1893b) On electric spark photographs; or photography of flying bullets etc, by the light of the electric spark II. Nature 47:445–446
Cooper GJ, Ryan JM (1990) Interaction of penetrating missiles with tissues: some common misapprehensions and implications for wound management. Br J Surg 77:606–610
De Veth C (1982) Development of a new second NATO calibre. The "5.56" with the SS109 projectile. Acta Chir Scand [Suppl] 508:129–134
DiMaio VJM (1985) Gunshot Wounds. Elsevier, Amsterdam New York, pp41–49
Fackler ML (1986) Wound Ballistics. In: Trunkey DD, Lewis FR (eds) Current therapy of trauma, pp94–101
Fackler ML (1987) What's wrong with the wound ballistics literature, and why. Institute Report No. 239, Letterman Army Institute of Research, Presidio of San Francisco
Fackler ML (1988) Wound ballistics: A review of common misconceptions. JAMA 259:2730–2736
Fackler ML (1989) Wounding patterns of military rifle bullets. Int Defence Rev 5:59–64
Fackler ML (1991) Errors and omissions. Wound Ballistics Rev 1:46
Fackler ML, Malinowski JA (1988) Internal deformation of the AK-74; A possible cause for its erratic path in tissue. J Trauma [Suppl] 28:S72–S75
Fackler ML, Surinchak JS, Malinowski JA, Bowen RE (1984a) Bullet fragmentation; A major cause of tissue disruption. J Trauma 24:35–39
Fackler ML, Surinchak JS, Malinowski JA, Bowen RE (1984b) Wounding potential of the Russian AK-74 assault rifle. J Trauma 24:263–266
Fackler ML, Malinowski JA, Hoxie SW, Jason A (1990) Wounding effects of the AK-47 rifle used by Patrick Purdy in the Stockton, California, schoolyard shooting of January 17, 1989. Am J Forensic Med Pathol 11:185–189
French RW, Callender GR (1962) Ballistic characteristics of wounding agents. In: Coates JB, Beyer JC (eds) Wound ballistics. Washington DC, Office of Surgeon General, Department of the Army, pp91–141
Hopkinson DAW, Marshall TK (1967) Firearm Injuries. Br J Surg 54:344–353
Janzon B (1983) High energy missile trauma. Dissertation, Bo Janzon, Göteborg
Janzon B, Berlin R, Nordstrand I (1979) Drag and tumbling behaviour of small calibre projectiles in tissue simulant. Acta Chir Scand [Suppl] 489:57–70
Kneubuehl BP, Maissen E (1978) Endballistik von Handfeuerwaffen, GRD, Fachabteilung 27, interner Bericht. In: Sellier K, Kneubuehl BP (eds) (1994) Wound ballistics and the scientific background. Elsevier, Amsterdam New York, p160
Knudsen PJT, Svender J (1994) Doppler radar velocity measurements for wound ballistics experiments. Int J Leg Med 107: 1–6
Knudsen PJT, Theilade P (1993) Terminal ballistics of the 7.62 mm NATO bullet, autopsy findings. Int J Leg Med 106:61–67
Moffat WC (1984) High velocity missile injuries. In: Taylor S et al (eds) Surgical Management. Heinemann, London, pp759–765
Nordstrand I, Janzon B, Rybeck B (1979) Break-up behaviour of some small calibre projectiles when penetrating a dense medium. Acta Chir Scand [Suppl] 489:81–90
Ryan JM, Cooper GJ, Maynard RL (1988) Wound ballistics: contemporary and future research. J R Army Med Corps 134:119–125
Sellier K, Kneubuehl BP (1994a) Wound ballistics and the scientific background. Elsevier, Amsterdam New York, pp62
Sellier K, Kneubuehl BP (1994b) Wound ballistics and the scientific background. Elsevier, Amsterdam New York, pp158–167
Tikka S, Lötjönen V, Cederberg A, Rokkanen P (1982) The behaviour of three standard small calibre projectiles in soap blocks. Acta Chir Scand [Suppl] 508:89–99
Warken D (1982) Untersuchungen zum Pendelverhalten ausgewählter kleinkalibriger Munition. Ernst Mach Institut 8/82, Fraunhofergesellschaft