Int J Legal Med (1997) 110 : 82–87

ORIGINAL ARTICLE

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The destabilizing effect of body armour on military rifle bullets

Received: 21 August 1996 / Received in revised form: 3 January 1997

Abstract Soft body armour is designed to give protection against fragments and some low velocity bullets but is not designed to stop high velocity rifle bullets. Reports have claimed that soft body armour might disturb the stability of bullets that penetrate it, and that this might increase the size of the lesions. The reason for such an effect might be early yaw of the bullet, so we studied the behaviour of bullets which had passed through soft body armour. A 7.62 × 39 mm AK-47 rifle was fired from a permanent stand using full metal jacketed lead core bullets at a range of 30 m. Soft body armour composed of 14 and 28 layers of aramid fibres (Kevlar) was placed at 90° and 60° to the line of fire. Yaw was measured by the shadowgraph technique and a TERMA Doppler radar. A total of ten shots without body armour, and ten shots with each of the two types of body armour at the two angles were used. The results of the shadowgraph and Doppler radar measurements showed a proportional correlation between the two methods of determining the bullet yaw. The semi-quantitative approach of the Doppler radar measurement was in agreement with the more concise measurement using the photographic technique. Velocity loss and loss of spin rate from penetrating 14 or 28 ply Kevlar was negligible. We observed induced instability after penetration of 14 and particularly 28 ply Kevlar, dependence of yaw with respect to the number of layers of Kevlar as well as to the angle of the body armour with respect to the line of fire.

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Key words Wound ballistics · Body armour · Bullet yaw · Bullet destabilization

Introduction

Soft body armour (fragmentation protective vests or flak jackets) provides considerable protection against some low velocity bullets and fragments. It is not designed to stop high velocity rifle bullets such as those fired from current military rifles. It has been claimed that soft body armour might even be deleterious when hit by such bullets, and that lesions might be augmented (Breteau et al. 1989). Some experiments have been reported (Missliwetz et al. 1995; Prather 1994), but no scientific documentation has been produced that can definitively prove or disprove this postulate. Since the mechanism behind such an augmented negative effect is assumed to be destabilization of the bullet, i.e. increase in yaw angle at impact with the body, we decided to study the behaviour of bullets that had passed through soft body armour. We have previously investigated the behaviour of such bullets in free flight (Knudsen and Sørensen 1995).

Material and methods

The weapon used for the experiments was a 7.62 × 39 mm AK-47 rifle of East German (Ex-GDR) manufacture made in 1962 (no. 62 J 2657). The weapon was in mint condition and was found to be in perfect working order. The bore measurements were 7.61 mm at the breech and 7.62 mm at the middle of the barrel and at the muzzle. With the ammunition used it had a dispersion of 9 cm at 40 m when fired in a permanent stand by remote control. The ammunition used was cartridges with full metal jacketed, lead core bullets made by LAPUA, Finland (7.62 × 39 Luoti S405 batch no. JIKW). The experiments took place in a 50 m shooting tunnel where the temperature was 18° C and the relative humidity 92%.

Two types of standard Danish military soft body armour were used, one composed of 14 layers of aramid fibres (Kevlar), and the other with 28 layers. The material (Kevlar 29 type 964) is produced by Verseidag Indutex GmbH, D 4150 Krefeld, Germany and has the designation W 7537. The areal density is 190 g/m^2 per layer, corresponding to 2.66 kg/m^2 for the 14-layer and 5.32 kg/m^2 for the 28-layer vest. The body armour was attached to a frame

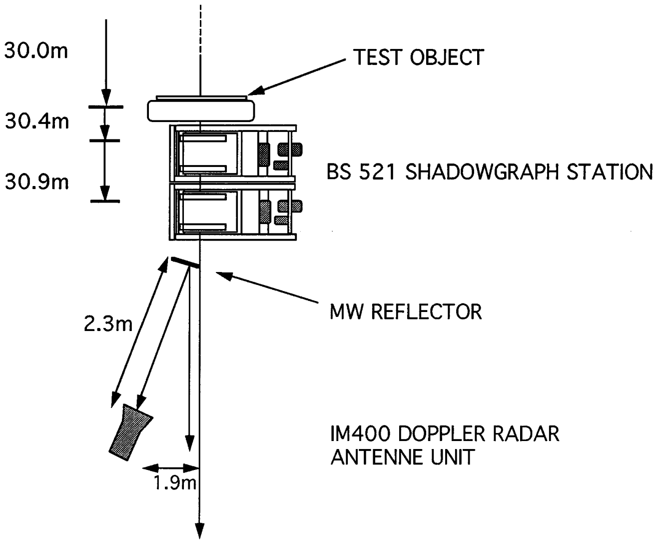


Fig. 1 The set up in schematic form

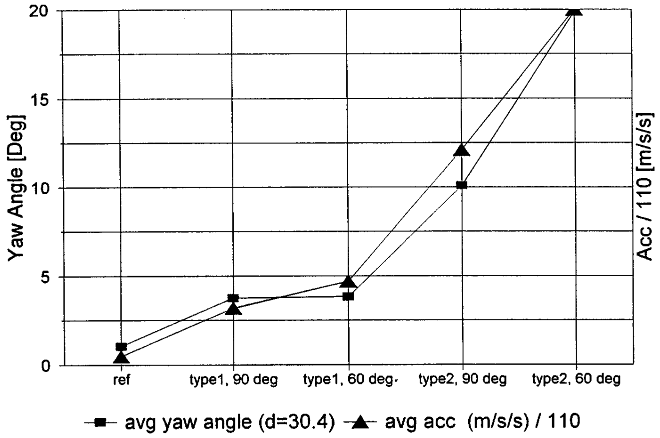


Fig. 2 Average results from the two methods

without tension, as in a real life situation and placed at angles of 90° and 60° to the line of fire at a distance of 30 m.

To measure the yaw angle we used two different methods. One was a photographic system using the Shadowgraph technique (Knudsen and Sørensen 1995; Warken 1983), the other used a 55 GHz TERMA Doppler radar to measure angular acceleration as a means of estimating the difference in yaw (Sørensen and Knudsen 1993; Knudsen and Svender 1994; Knudsen et al. 1996) (Fig. 1). At present the latter is only a semi-quantitative stage technique. We fired ten reference shots without body armour, and ten shots each with the two types of body armour at the two angles.

To measure the yaw angles on the photographs, a NIKON Profile Projector Model 6c was used giving the possibility of determining yaw angles directly from the negatives, eliminating the need for large size black and white photos and the risk of losing precision in the process.

The Doppler radar in conjunction with the TERMA DR5000 Velocity Analyzer can give data in a variety of modes. For our use the digitized value of the acceleration behaviour was used, the relevant measurement being the amplitude of the first modulated wave after passing through the body armour. The set-up as shown in Fig. 1 was carefully adjusted to ensure that the test equipment did not affect the flight behaviour of the bullet. Yaw was measured in a semiquantitative way by means of the high frequency Doppler radar system. The combination of a high transmitter frequency and suitable FFT data processing revealed a modulation on the acceleration data caused by projectile yaw. As seen in Figs. 3–7 such analyses do not only provide an instant value, but also show the stabilizing effect as a function of time. In these experiments we have correlated the photographic registration with a Doppler radar in order to determine a correlation between the measurements obtained with the two systems.

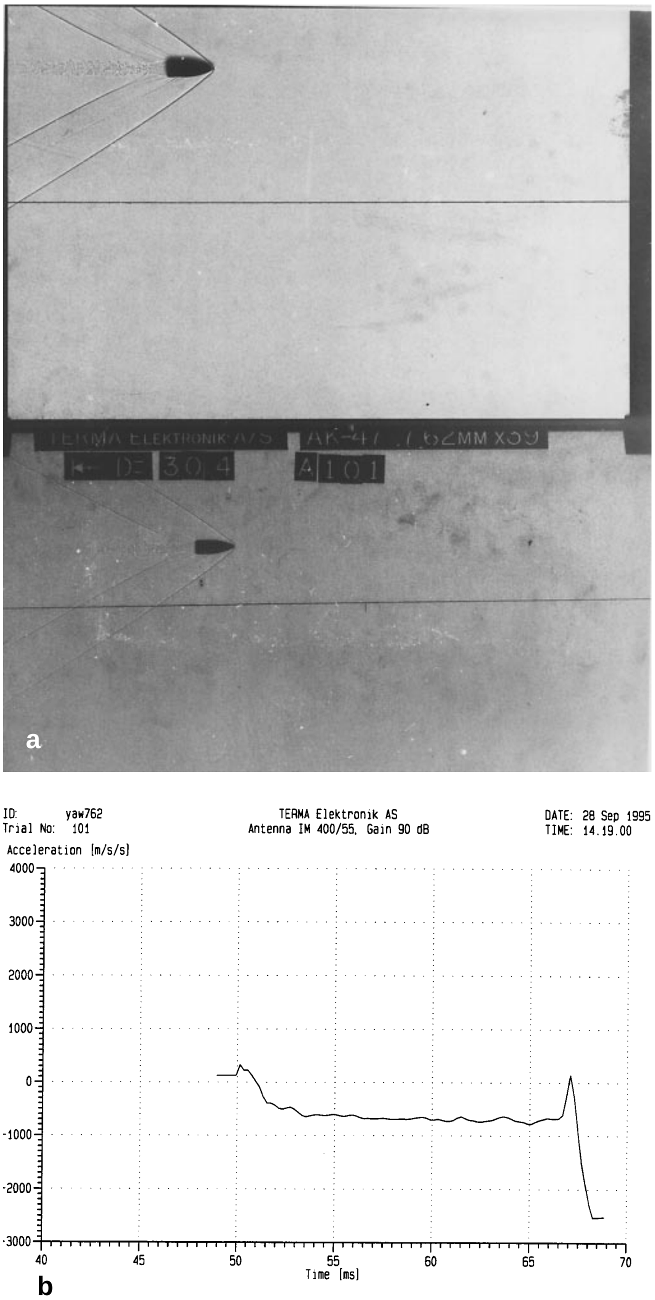
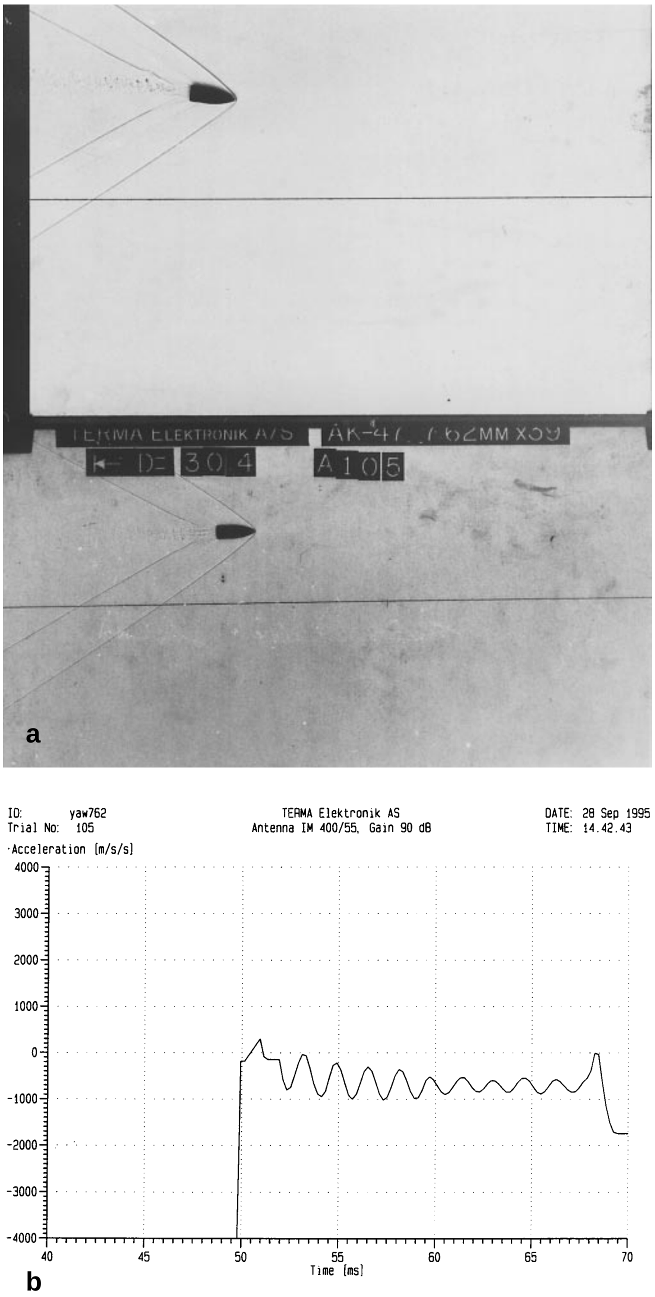


Fig. 3 **a** Photo and **b** print-out of reference shot without body armour at 40 m: 0° yaw and acceleration modulation ≤ 50 m/s^2

Results

Initially a large number of shots were fired at both types of body armour to measure loss of velocity and loss of spin rate. Both parameters decreased with a value of less



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Trial No: 105
TERMA Elektronik AS
Antenna IM 400/55, Gain 90 dB
DATE: 28 Sep 1995
TIME: 14.42.43

Fig. 4 **a** Photo and **b** print-out of reference shot with 14-layer body armour at 90° to the line of fire at 40 m: 6.8° yaw and acceleration modulation 777 m/s^2

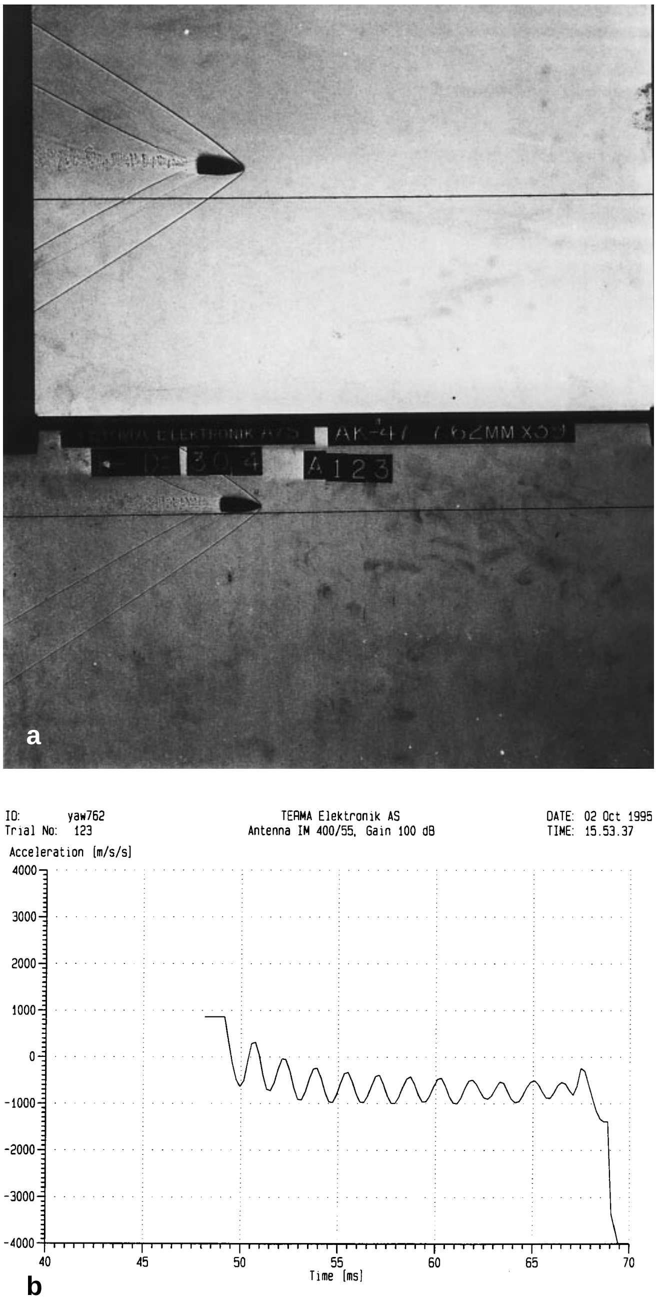

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Fig. 5 **a** Photo and **b** print-out of reference shot with 14-layer body armour at 60° to the line of fire at 40 m: 5.6° yaw and acceleration modulation 827 m/s^2

than 1% when passing through the soft body armour panels, and we judged this change to be negligible. Similar results have been reported by Prather (1994).

The results of the shadowgraph and Doppler radar measurements are summarized in Tables 1 and 2 and in Fig. 2. For the shadowgraph measurements we estimated the accuracy to be 0.2° or better. We believe that this level of accuracy is satisfactory when compared with the variations in yaw, which in one set of experiments were two-digit values in degrees. We only had two shadowgraph stations at our disposal, not the multitude of stations available to other workers (Warken 1983). Based on theoretical considerations of the yaw cycle and previously measured data we placed the two shadowgraph stations at such a distance from each other that at least one of them would be near the maximum of the yaw cycle. We believe we have succeeded in obtaining a reliable result when comparing them to previous experiments where the same rifle was fired from different ranges (Knudsen and Sørensen 1995).

Doppler radar measurements, where the modulation in amplitude was negligible – 50 m/s^2 or less – have all been

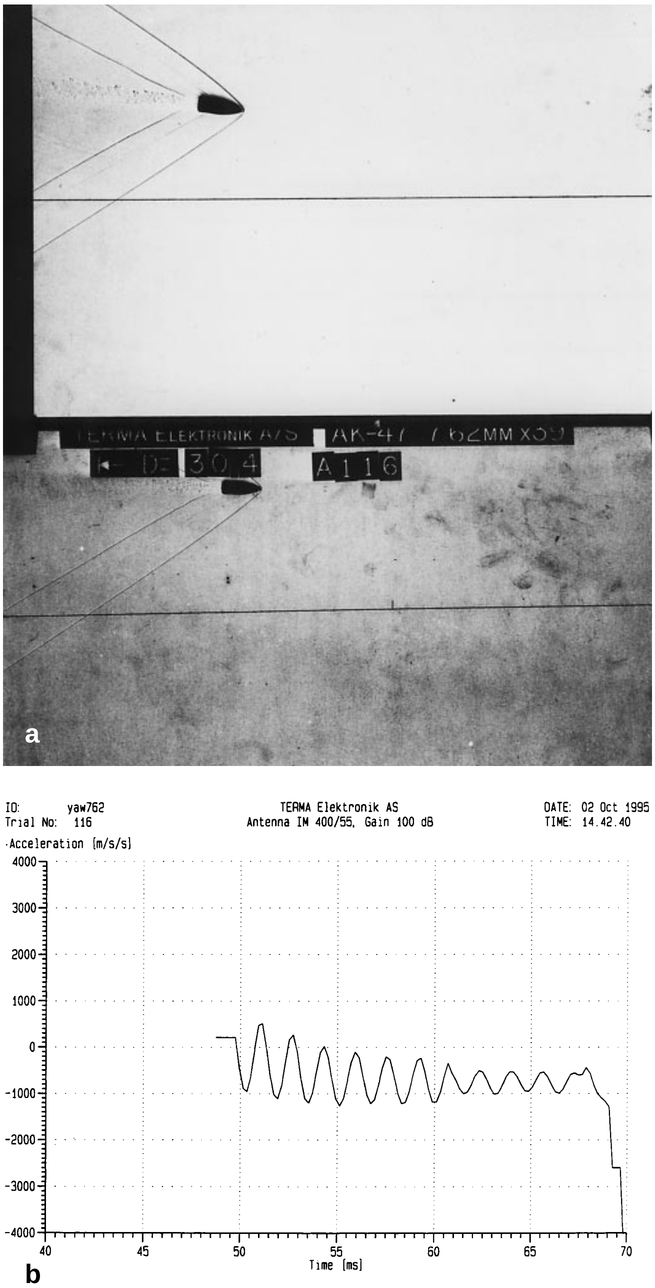

Fig. 6 **a** Photo and **b** print-out of reference shot with 28-layer body armour at 90° to the line of fire at 40 m: 9.4° yaw and acceleration modulation 1472 m/s^2

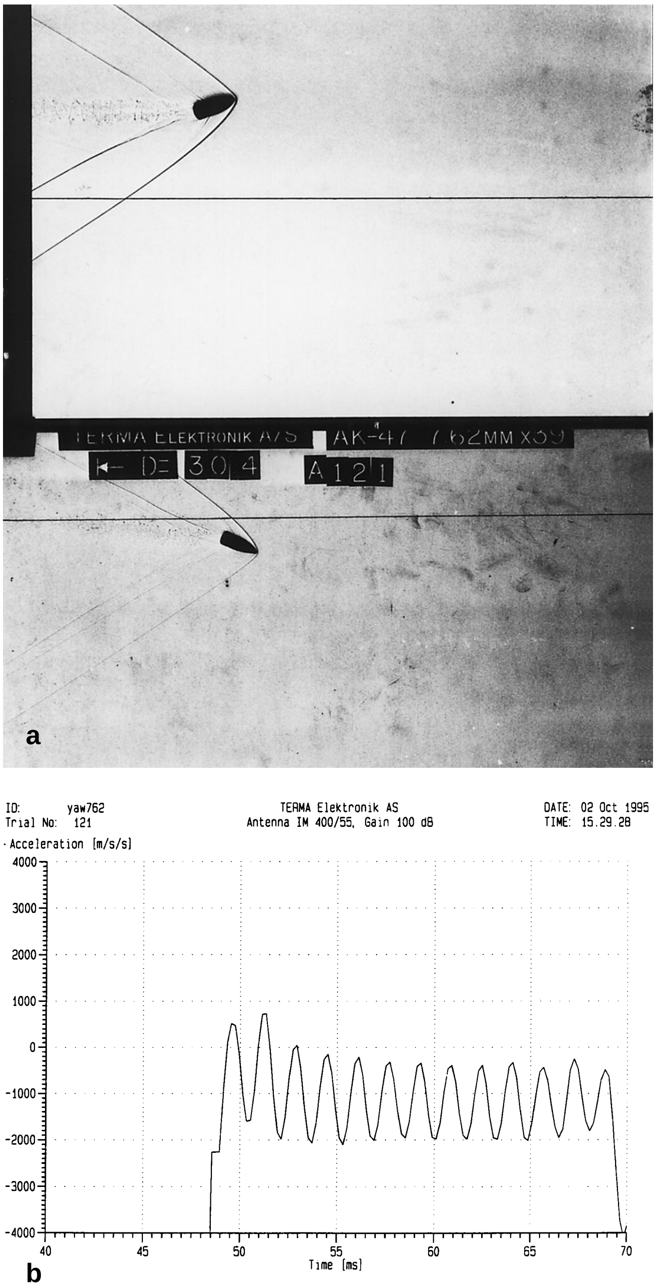

Fig. 7 Photo and print-out of reference shot with 28-layer body armour at 60° to the line of fire at 40 m: 18.7° yaw and acceleration modulation 2340 m/s^2

grouped in one group of 50 m/s^2. We have not made an adjustment of this in the statistical analyses of the results, the reference shots thus being assigned a higher acceleration as compared with other groups. However 50 m/s^2 is very low compared to the results in general and this should not disturb the general picture.

There appears to be a proportional correlation between the two methods of determining the bullet yaw, the semiquantitative approach of the Doppler radar measurement fitted well with the more concise measurement using the photographic technique. By dividing the acceleration values by 110, the curve of yaw in degrees at 30.4 m closely matched the acceleration values (Fig. 2). The impression of yaw from the photos is also in good accordance with the results of the Doppler radar measurements. The corresponding photos and graphs are shown in Figs. 3–7.

While the average values indicate a good correlation between the two types of measurement, it should be noted that there is a quite large variation between the maximum and minimum values registered both by the shadowgraph and the Doppler radar technique, so we feel that at least

Table 1 Results of measurements in degrees, average and min/max values

Range	Reference	14 ply 90°	14 ply 60°	28 ply 90°	28 ply 60°
30.4 m	1.04° (0–2.62°)	3.76° (1.77–9.92°)	3.83 (1.17–6.92°)	10.08° (0.4–20.8°)	19.88° (6.89–38.28°)
30.9 m	0.95° (0–1.68°)	1.43° (0.5–4.28°)	1.44 (0–2.2°)	2.55° (0– 5.03°)	4.88° (2.12–6.94°)

Table 2 Results of measurements in m/s^2, average and min/max values

	Reference	14 ply 90°	14 ply 60°	28 ply 90°	28 ply 60°
Exit	52.22 (50–70)	346.84 (53–777)	518.20 (50–1310)	1333.10 (80–2340)	2201.60 (1409–4254)

ten shots should be used if a reliable average is to be attained. One shot at the 28-layer vest had a very minimal yaw angle, and we contemplated leaving it out as a "lucky shot" but decided to retain it as an example of one of the possible pitfalls in the methods: the large variation in the results, as has been the experience of other workers (Missliwetz et al. 1995).

Apart from proving the agreement between the two different methods and to calibrate the Doppler radar method we used the Doppler radar to dispel the idea that the bullets had turned over in flight. The graphical presentation of the Doppler radar results showed that the bullets tended to return to their proper attitude in flight, at the same time disproving the allegation that the spin/axial rotation of the bullet had been significantly reduced by passing through the body armour.

Discussion

When a soldier or police officer is ordered to wear protective equipment such as a fragment protective vest, the foremost concern of the authority giving this order is whether the equipment will perform as expected. But a secondary concern is to assure that it will not be harmful to the user when used for its intended purpose, and if possible, when it is exposed to a more severe test than it was designed for. The military fragment protective vest – the "flak jacket" – is designed to stop fragments and to stop some low velocity handgun bullets and shotgun pellets if their mass and velocity are within the design envelope of the material. The vest is normally penetrated by some pistol bullets at close range as well as nearly all high velocity military type rifle bullets fired from a quite considerable distance. It has been claimed that penetration of soft body armour by high velocity rifle bullets will lead to increased size of lesions as compared to unprotected penetration (Breteau et al. 1989; Fackler 1996). Other workers have not been able to demonstrate this and claim that the difference is negligible (Prather 1994) and still others have indicated the complexity of the question and not given a definitive answer (Missliwetz et al. 1995).

The most plausible explanation of an increased size of lesions would be an increase in the yaw angle due to destabilization of the bullet by the impact of the bullet with the body armour. The yaw angle mentioned is referred to in aeroballistic terms, ie. the total angle of incidence that the projectile makes with the line of fire (Textbook of ballistics and gunnery 1987). The bullet striking the target at a greater yaw angle after penetration of the body armour causes an earlier turning-over of the bullet in the target and a higher energy deposit and thus a greater potential for damage (Missliwetz et al. 1995; Sellier and Kneubuehl 1994).

The results of our experiments are not surprising. It is interesting that similar results have not previously been documented in unclassified publications. The essential question is to what extent the destabilization may be assumed to lead to greater injuries. Until the day that the results of experiments in tissue simulants are available, we may to some extent judge the effect by comparing the yaw angles of the destabilized bullets with the yaw angles of bullets previously investigated by us (Knudsen and Sørensen 1995). If we compare our present results to those of the 7.62 mm NATO bullet we find that the yaw angle of the 7.62 mm × 39 AK-47 bullet after penetration of 14 layers Kevlar at both angles investigated (see Table 1) is similar to that of the 7.62 mm NATO bullet at 30 m, yaw angle 4.11° [2.05°–6.38°]. It is therefore reasonable to assume that the lesions caused by the AK-47 bullet after penetration of the ordinary fragment protective vest would be of a size equivalent to an unprotected shot from a 7.62 mm NATO bullet at a similar range. The lesions from the AK- 47 would probably be even less, since this bullet is known to show a more stable flight behaviour than the NATO bullet (Knudsen and Sørensen 1995), and would probably still turn later in the target after penetration of the fragment protective vest than an undisturbed NATO bullet. The effect of shooting through 28 layers at 90° or especially at 60° is very different. The *average* yaw angle of the AK-47 bullet after penetration of the fragment protective vest at 90° is greater than the maximum yaw angle we have measured at any range earlier – the *maximum* being 9.72° in case of the 5.45 mm × 39 AK-74 at close range, and if we fire at 60° the difference is even more striking. Even taking into account the greater stability of the AK-47 bullet in contrast to the 5.56 mm and 5.45 mm bullets, it must be assumed that the lesions of the AK-47 bullet would be far greater in a target wearing the 28-layer than in the unprotected target or that covered by the 14-layer fragment protective vest. Our experiments show unequivocally that destabilization takes place increasingly as the thickness and/or angling of the soft body armour is increased. It is now desirable to examine if this destabilization will produce larger lesions, for example by firing into tissue simulants such as ordnance gelatin or soap and noting the change in the wound channel, particularly the length of the "neck" or "narrow channel" of the bullet's trajectory. If the neck is shortened and if the length of the channel as a whole is shortened, this means that more kinetic energy per unit length has been deposited and thus that more energy has been available for destroying tissue in the first 30 cm that correspond to the thickness of a fully dressed adult human being.

Such a study would also address one of the main limitations of our work, namely that the body armour was fired upon without any backing to support it. It might be argued that the backing material might modify the behaviour of the bullet, but for the experiments presented here, we wanted to investigate the effect of the body armour on the stability of the bullets exclusively.

Due to the concern voiced elsewhere (Breteau et al. 1989) the Danish Armed Forces have deleted the option of using 28 layers for fragment protective jackets, a policy which is supported by our investigation.

Acknowledgements The assistance of the Danish Army Combat School is gratefully acknowledged, the opinions in this paper are those of the authors and should not be construed to represent the opinion of the Danish Armed Forces. Previously presented in part at the Personal Armour Systems Symposium, Colchester, UK, 2–6 September 1996 and the 16th International Symposium on Ballistics, San Francisco, USA, 23–28 September 1996.

References

Breteau J, Fackler ML, Sendowski I, Martin P (1989) The personal protective equipment provided for combatants: the part played by wearing a protection vest in the behaviour of projectiles. Wounding outcomes. Proceedings of the 11th International Symposium on Ballistics, Brussels, 9–11 May 1989, Vol. III, pp 9–18

Fackler ML (1996) Commentary on Missliwetz J, Denk W, Wieser I. Study on the wound ballistics of fragmentation protective vests following penetration by handgun and assault rifle bullets, J Forensic Sci 1995;40:582–84. J Forensic Sci 41:349–350

Knudsen PJT, Svender J (1994) Doppler radar velocity measurements for wound ballistics experiments. Int J Legal Med 107: 1–6

Knudsen PJT, Sørensen OH (1995) The initial yaw of some commonly encountered military rifle bullets. Int J Legal Med 107: 141–146

Knudsen PJT, Svender J, Sørensen OH (1996) New technology in wound ballistics: the Doppler radar. J Trauma 40:S42–S45

Missliwetz J, Denk W, Wieser I (1995) Study on the wound ballistics of fragmentation protective vests following penetration by handgun and assault rifle bullets. J Forensic Sci 40:582–584

Prather R (1994) Small arms vs. soft armour: a pilot study. Proceedings of the Personal Armour Systems Symposium, 21–25 June 1994, Colchester UK, pp 137–141

Sellier K, Kneubuehl BP (1994) Wound ballistics and the scientific background. Elsevier, Amsterdam London New York Tokyo, pp 131–168

Sørensen OH, Knudsen PJT (1993) A new method of estimating yaw of small calibre bullets using Doppler Radar. Proceedings of the 41st Meeting of the Aeroballistic Range Association, Munich, 12–19 September 1993

Textbook of Ballistics and Gunnery, Part one: Basic Theory (1987). HMSO, London, p 446

Warken D (1983) Untersuchungen zum Pedelverhalten ausgewählter kleinkalibriger Munition. Ernst Mach Institut 8/82, Fraunhofergesellschaft