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REVIEW ARTICLE

Damage to apparel layers and underlying tissue due to hand-gun bullets

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Abstract Ballistic damage to the clothing of victims of gunshot wounds to the chest can provide useful forensic evidence. Anyone shot in the torso will usually be wearing clothing which will be damaged by the penetrating impact event and can reportedly be the source of some of the debris in the wound. Minimal research has previously been reported regarding the effect of bullets on apparel fabrics and underlying tissue. This paper examines the effect of ammunition (9 mm full metal jacket [FMJ] DM11 A1B2, 8.0 g; and soft point flat nose Remington R357M3, 10.2 g) on clothing layers that cover the torso (T-shirt, T-shirt plus hoodie, T-shirt plus denim jacket) and underlying structures represented by porcine thoracic wall (skin, underlying tissue, ribs). Impacts were recorded using a Phantom V12 high speed camera. Ejected bone debris was collected before wound tracts were dissected and measured; any debris found was recovered for further analysis. Size and mass of bony debris was recorded; fibre debris recovered from the wound and impact damage to fabrics were imaged using scanning electron microscopy (SEM). Remington R357M3 ammunition was characteristically associated with stellate fabric damage; individual fibres were less likely to show mushrooming. In contrast, 9 mm FMJ ammunition resulted in punch-out damage to fabric layers, with mushrooming of individual fibres being more common. Entry wound sizes were similar for both types of ammunition and smaller than the diameter of the bullet that caused them. In this work, the Remington R357M3 ammunition resulted in larger exit wounds due to the bullet construction which mushroomed. That fabric coverings did not affect the amount of bony debris produced is interesting, particularly given there was some evidence that apparel layers affected the size of the wound. Recent work has suggested that denim (representative of jeans) can exacerbate wounding caused by high-velocity bullet impacts to the thigh when the bullet does not impact the femur. That more bony debris was caused by Remington R357M3 rather than 9 mm FMJ ammunition was not surprising given the relative constructions of these two bullets, and is of interest to medical practitioners.

Keywords Clothing · Handguns · Bullets · Bony wounds

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Introduction

Seventy percent of the firearm incidents in the United Kingdom to the year ending September 2010 involved a handgun, resulting in 41 deaths (n=33 male)[1].While wounds caused by bullets from handguns are usually medically less critical than those caused by bullets from rifles, any penetrating impact to the torso can involve damage to critical organs [2–7]. Rib fracture does not necessarily occur during penetrating incidents, but rib fractures may themselves cause more serious injuries [7–11]. Bevelling of bony bullet wounds can indicate direction of travel and impact angle [12], e.g., a bony rib wound described in a review of 27 cases of skeletal trauma (n=39 wounds) had an external to inner area of damage ratio of 1.19 mm; asymmetrical internal bevelling was noted [13]. Recreating penetrating ballistic events is of benefit to the forensic and medical communities and there is some discussion as to the most suitable simulants. Forensic recreations of ballistic impact events typically use butchered porcine material to represent the human torso [14–17].

Anyone shot in the torso will usually be wearing clothing, which will be damaged by the penetrating impact event. That fibre and fabric debris is often found in wound tracts is widely recognised [2, 8, 10, 14–17]. Metallic debris retained in ribs has recently been investigated [18, 19]. Such debris can be used as forensic evidence [20]. Debris, including clothing fragments, can be a cause of infection [2, 8, 16, 17] with the lungs being particularly vulnerable to organic debris such as clothing fragments [11]. Lead toxicity of retained bullet fragments may be an issue in the long term, particularly if absorbed by serosal or synovial tissue rather than muscle [21, 22]. Whether bullet type affects fibre/fabric debris does not seem to have been reported.

There are limited studies discussing damage caused to apparel fabrics by bullets, exceptions include [20, 23–26]; studies that do exist lack in key details. The effect of firing a Remington 0.22-caliber rimfire bolt-action rifle, a Colt Woodsman 0.22-caliber rim-fire auto-loading pistol and a Winchester Model 94 0.30–30 lever-action rifle (ammunition details not provided) at cotton fabrics (denim, broadcloth, jersey knit; no further details provided) and at distances varying between close contact and 6 m has been reported [25]. Stellate damage did not occur with the 0.22 rifle. In comparison, 0.22 pistol ammunition resulted in stellate damage when in contact with the fabric (close and loose) and 30–30 rifle ammunition resulted in stellate damage at less than 80 mm range. Poole and Pailthorpe [23] compared impacts using a Winchester Superspeed 0.22 long rifle (solid point bullets at 350 m/s; hollow-point bullets at 400 m/s) on apparel at contact and from a distance of 200 mm. The apparel tested were single jersey cotton T-shirt, single jersey polyester vest, plain weave polyester cotton shirt, warp knit nylon slip and single jersey wool jumper. Whether the garments were new or laundered was not reported. All shots penetrated the targets resulting in a ring of gun-shot residue surrounding the bullet holes. The shape of bullet holes in the fabrics was more clearly defined for less elastic fabrics, i.e., fabric structure affected morphological macro-features of the damage. The effect of ammunition fired from a Tokarev (7.62 mm), a Makarov (9 mm) and a Glock 19 (9 mm) at cotton and polyester fabrics (no further details provided) mounted on human cadaver thigh skin at distances of 100, 150, and 250 mm on the 'injuries', soot and gunpowder depositions, and fabric damage has been investigated [24]. For all weapons, the polyester fabric showed melting at the edges of the holes caused by the bullets; more melting occurred with the Tokarev. All bullet holes in the fabrics were round, without tears. Fibre debris in the human tissue was more commonly observed with the cotton fabric. Gunpowder and soot debris were commonly observed on the skin surface and in the wound. Debris on the fabric surface generally covered a greater area on the cotton fabric. Damage to a shirt worn by the victim of a shooting incident was briefly described as being a hole 50×55 mm in size with singed edges; but no details were provided of the fibre/fabric types [26].

The aim of this work was to investigate the effect of penetrating handgun bullets on (1) the damage caused to fabrics used in apparel that covers the torso and (2) fibre, fabric and bony debris located in the wound tract of underlying tissue.

Materials and methods

Materials

Three common apparel fabrics were chosen, all were 100 % cotton to standardise for fibre type (Fabric Magic, Trowbridge, Wiltshire, UK; Vend Fabrics Ltd., Leicester, UK). Fabrics were (1) jersey knit (T-shirt), (2) jersey knit, brushed technical rear (hoodie or sweatshirt) and (3) denim (denim jacket). Dimensionally stable fabrics were obtained by laundering for 6 cycles according to section 8A of BS EN ISO 6330/A1:2009 and flat-drying after the sixth cycle according to section 10C of the same protocol [27, 28]. Mass per unit area and thickness were measured before and after laundering for single layers and for combined layers as might be worn (T-shirt plus hoodie; T-shirt plus denim jacket) (Table 1) [29–31]. Laundered fabrics were cut to fit individual porcine material, minimising repetition of wales or warp and course or weft yarns among specimens, and not within 50 mm of the manufactured edge [32]. Fabric specimens were conditioned for 24 h prior to testing at a temperature of 20±2°C and a relative humidity of 65±4 % [33]. Specimens were tested to mimic the arrangement of apparel as worn: (1) T-shirt, (2) T-shirt plus hoodie and (3) T-shirt plus denim jacket; either the warp or wale direction was arranged vertically.

Methods

Fabric specimens were mounted onto porcine thoracic wall specimens (i.e., skin, underlying tissue, ribs) (Andrews Quality Meats Ltd., Highworth, Wiltshire, UK).[1] Forensic

[1] Belly rib sections were prepared by cutting through the intercostal space between rib numbers 3 and 4 and below the lowest rib for each animal. Back rib sections were not included.

Table 1 Fabric properties

Specimen	As new			Laundered		
	Mean	SD	CV (%)	Mean	SD	CV (%)
Mass per unit area (g/m^2)						
T-shirt	159.69	4.44	2.78	170.54	2.86	1.68
Hoodie	274.91	7.26	2.64	362.79	8.58	2.36
Denim	401. 58	1.24	0.31	411.25	7.11	1.73
T-shirt plus hoodie	434.74	6.20	1.43	530.36	9.62	1.81
T-shirt plus denim	525.83	8.11	1.54	569.93	19.34	3.39
Thickness (mm)						
T-shirt	0.494	0.011	2.23	0.532	0.013	2.45
Hoodie	1.240	0.035	2.82	1.836	0.065	3.54
Denim	0.899	0.021	2.34	0.908	0.040	4.41
T-shirt plus hoodie	1.774	0.098	5.52	2.300	0.052	2.24
T-shirt plus denim	1.386	0.033	2.38	1.422	0.045	3.20

recreations of ballistic impact events typically use butchered porcine material to represent the human torso, even though there are structural and physical differences between humans and pigs [14–17]. In this work, the effect of bullet and fabric covering types on debris formation in the bony wound was the primary area of interest rather than the actual mechanism of the wound formation, although wound data was collected. The porcine material used varied in width from 170 to 200 mm, in length from 340 to 420 mm and in thickness from 31 to 49 mm. Pigs typically have between 13 and 17 pairs of ribs; this is primarily affected by breed, age and sex, but variation does occur within a farrow (litter) [34].The pigs used in this work had between 13 and 15 ribs.

Two types of ammunition were used for testing (1) 9 mm FMJ (full metal jacket; DM11 A1B2; 8.0 g) and (2) Remington R357M3 (soft point flat nose; Remington R357M3; 10.2 g) (Fig. 1a).These two types of handgun ammunition are those most typically observed in the UK and are the ammunition used to test UK police officers' body armour [35].The effective range of typical handgun ammunition to ensure reasonable accuracy is generally less than 20 m; engagement distances for police officers shot in the USA is typically <5 m. In the current study, a No. 3 Enfield proof housing fitted with appropriate barrels was used to fire the ammunition from a range of 5 m at the fabric specimens mounted on the porcine material (Fig. 1b and c).The use of a proof housing improves accuracy and reproducibility of shot, thus improving probability of hitting a rib with each bullet. Two rounds were fired at each porcine material specimen, one of each ammunition type; the impact position (top, bottom) was varied among ammunition types and fabric specimens. The objective was for each bullet to penetrate the fabric specimen and underlying porcine material, thus creating a penetrating wound tract. Impact velocities

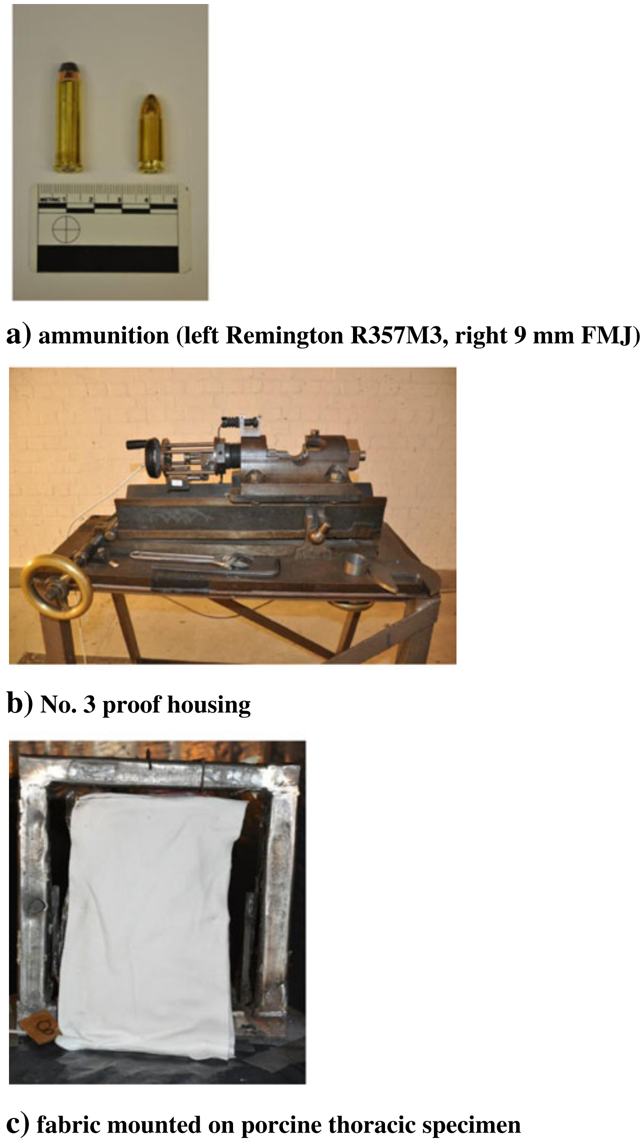


Fig. 1 Experimental apparatus. **a** Ammunition (*left* Remington R357M3, *right* 9 mm FMJ). **b** No. 3 proof housing. **c** Fabric mounted on porcine thoracic specimen

were recorded using a Weibel W-700 Doppler radar, while a Phantom V12 high-speed video camera was used to record the impact event from the front and rear of the specimens.

Analysis

Bone debris ejected from the porcine material as a result of testing was collected, weighed and photographed using a Nikon D90 camera fitted with a Nikon DX VR AF-S NIKKOR18-105-mm lens. Damage to porcine material (entry and exit wounds; maximum height and width at outer surface; Fig. 2a and b) was measured and photographed before dissection (Fig. 2c). The wound tract length and maximum wound tract height were measured (Fig. 2d). Bone and fibre debris

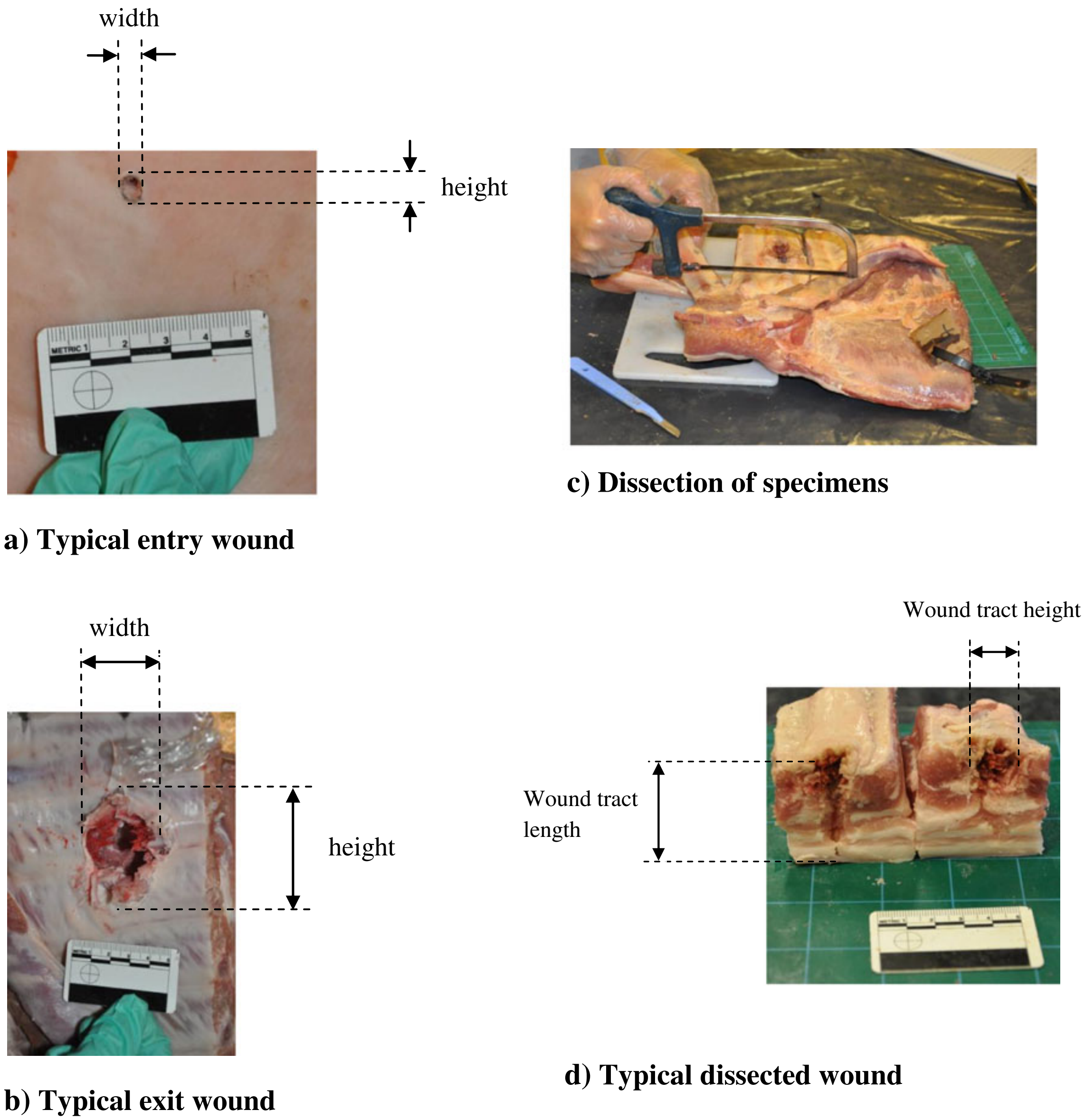


Fig. 2 Typical examples of damage to porcine material. **a** Typical entry wound. **b** Typical exit wound. **c** Dissection of specimens. **d** Typical dissected wound

recovered during dissection of the wound tracts were collected, weighed and photographed. The effect of fabric coverings on wound dimensions and bony fragments was determined using analysis of variance (ANOVA) and Tukey's HSD test (IBM SPSS Statistics 19). Dried fabric specimens were mounted on aluminium stubs with double sided carbon tape and coated with 10 nm of carbon using an Emitech 250x carbon coater attachment. Elemental analysis on fabric specimens was carried out using a JEOL JED 2300 F energy dispersive spectrometry (EDS) detector (25 kV) using point and area analyses; areas were identified using a backscatter detector. Specimens were then sputter coated with gold palladium using an EmitechK575X Peltier-cooled high resolution sputter coater and fabric damage investigated using a JEOL 6700 F field emission scanning electron microscope (FESEM; 3 kV, 9–12 mm working distance) and a Cambridge 360S SEM (3 kV, 35–37 mm working distance).

Results and discussion

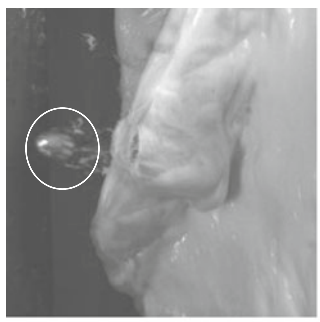
Bullets

The mean impact velocity for 9 mm FMJ bullets was 360.37 (SD=4.79) m/s and for Remington R357M3 bullets was 383.12 (SD=4.27) m/s. These values compare favourably to published velocities of 365±10 and 390±10 m/s, respectively [35]. High-speed video footage suggested that the bullets did not fragment on impact with ribs and appeared to exit the inner surface of the porcine thoracic wall largely intact (Fig. 3). The Remington R357M3 bullets were mushroomed when they exited the porcine material; however the 9 mm FMJ bullets were not deformed (Fig. 3). Analysis of individual frames from the high speed video revealed that there was no evidence of a fabric plug on the nose of either type of bullet (Fig. 3).

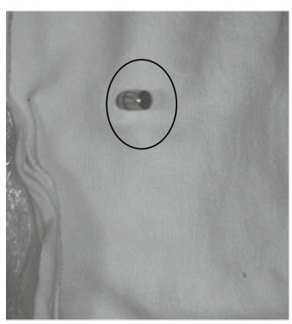
Sixteen whole or parts of the 32 bullets fired (four 9 mm FMJ; three Remington R357M3 jacket plus core combined; five Remington R357M3 jackets; four Remington R357M3 cores) were recovered from the sand trap at the rear of the ballistic test range (Fig. 4; Table 2). The masses of the bullets recovered in this work can be compared favourably to data in the literature for not-fired bullets, e.g., 9 mm FMJ bullets 8.0 g [36] and 8.000 (SD=0.009) g, 8.022 (SD=0.008) g, 8.017 (SD=0.006) g [37]; and Remington R357M3 10.2 g [36]. Thus, although the bullets appeared intact on the high speed video as they exited the ribs the recovered bullets were lighter (particularly for the Remington R357M3 ammunition); however this could have been due to interaction with the sand trap. The variability in the mass of recovered Remington R357M3 ammunition was larger than for 9 mm FMJ bullets (CV=23.17 %; CV=3.10 %), suggesting the Remington R357M3 ammunition was more vulnerable to fragmentation on impact.

Fabric damage

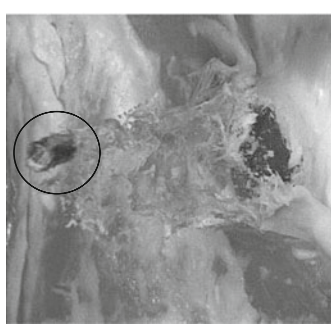
After impact, holes were visible in fabric layers, surrounded by a ring of bullet wipe [12, 38] (Fig. 5a). Semi-quantitative EDS analysis identified lead (80–90 %), copper (6–10 %),



a) **intact 9 mm FMJ bullet exiting specimen**



b) **Remington R357M3 bullet impacting specimen**



c) **Remington R357M3 bullet exiting specimen –evidence of mushrooming**

Fig. 3 Typical stills from high-speed video. **a** Intact 9 mm FMJ bullet exiting specimen. **b** Remington R357M3 bullet impacting specimen. **c** Remington R357M3 bullet exiting specimen — evidence of mushrooming

Fig. 4 Typical examples of recovered bullets, jackets and cores (*top row* Remington R357M3 cores, *middle row* Remington R357M3 jackets, *bottom row* 9 mm FMJ)

potassium, calcium and sodium in the vicinity of the bullet wipe ring. Holes in thinner fabrics (single jersey) were clearer than thicker fabrics (hoodie and denim) (Fig. 5b–d). Stellate damage was more commonly observed for Remington R357M3 impacts rather than 9 mm FMJ impacts (Fig. 5b–c). The 9 mm FMJ round was more likely to punch through the fabric layers, compared to the Remington R357M3 round, which tore through layers. Some fibres appeared mushroomed, but on closer examination of the fracture surface, the fibre appeared to have wrapped itself around the bulk fibre possibly due to elastic recovery; some fibres had the appearance of having been cut or torn (Fig. 5e–h). Individual fibre 'mushrooming' was more likely to occur when fabrics were impacted by the 9 mm FMJ round.

Table 2 Mass of recovered bullets, jackets and cores (g)

9 mm FMJ
7.6843
7.4136
7.9783
7.4680
Remington R357M3
9.3232
9.6005
6.1224
Remington R357M3 jackets
1.3990
2.5698
1.3938
1.4794
2.0314
Remington R357M3 cores
7.3708
7.9104
7.8884
8.1920

Bony wounds

Wound dimensions are presented in Table 3.

Mean linear wound (entry and exit data combined) dimensions did not vary whether measured in a horizontal or vertical direction as viewed after the impact event ($F_{1, 96}$=3.21, p=NS). However, the mean dimension of the wound was affected by whether the wound was measured on the entry or exit face of the porcine material, the ammunition type used and the fabric type(s) covering the strike face ($F_{1, 96}$=844.73, $p \leq 0.001$; $F_{1, 96}$=234.24, $p \leq 0.001$; $F_{3, 96}$=9.51, $p \leq 0.001$). The mean dimension for the entry wound was 5.42 mm (SD=1.34 mm) compared to the mean dimension for the exit hole of 27.34 mm (SD=13.29). In this work, the Remington R357M3 ammunition resulted in larger wounds than the 9 mm FMJ ammunition (mean dimension=22.16 mm, SD=17.57 mm; mean dimension=10.61 mm, SD=6.73 mm). Fabric covering affected the mean wound size significantly, although weakly, compared to specimens with no fabric covering. Mean wound dimensions were smaller (but with large variability regardless of whether a covering was present or not; i.e., CV=87–88 %) when porcine material had a fabric covering, but Tukey analysis could not distinguish among the fabric coverings (T-shirt mean=14.03 mm, SD=12.21 mm; hoodie plus T-shirt mean=15.91 mm, SD=14.03 mm; denim plus T-shirt mean=16.02 mm, SD=14.03 mm; no coverings mean=19.59 mm, SD=17.26 mm). Noticeably, mean wound size was smaller (although not significantly so) as the fabric coverings became stiffer.

The type of ammunition used affected the size of the wound differently on the entry and exit faces ($F_{3, 96}$=206.45, $p \leq 0.01$). Both ammunition types resulted in an entry hole of approximately 5 mm mean 'diameter' (9 mm FMJ=5.08 mm; Remington R357M3=5.78 mm); the mean exit hole 'diameter' for 9 mm FMJ ammunition was 16.16 mm (SD=5.22 mm) whilst the Remington R357M3 ammunition resulted in a much larger exit hole of 38.53 mm (SD=8.55 mm). The use of the word 'diameter' is somewhat contentious as the statistical analysis also suggested that

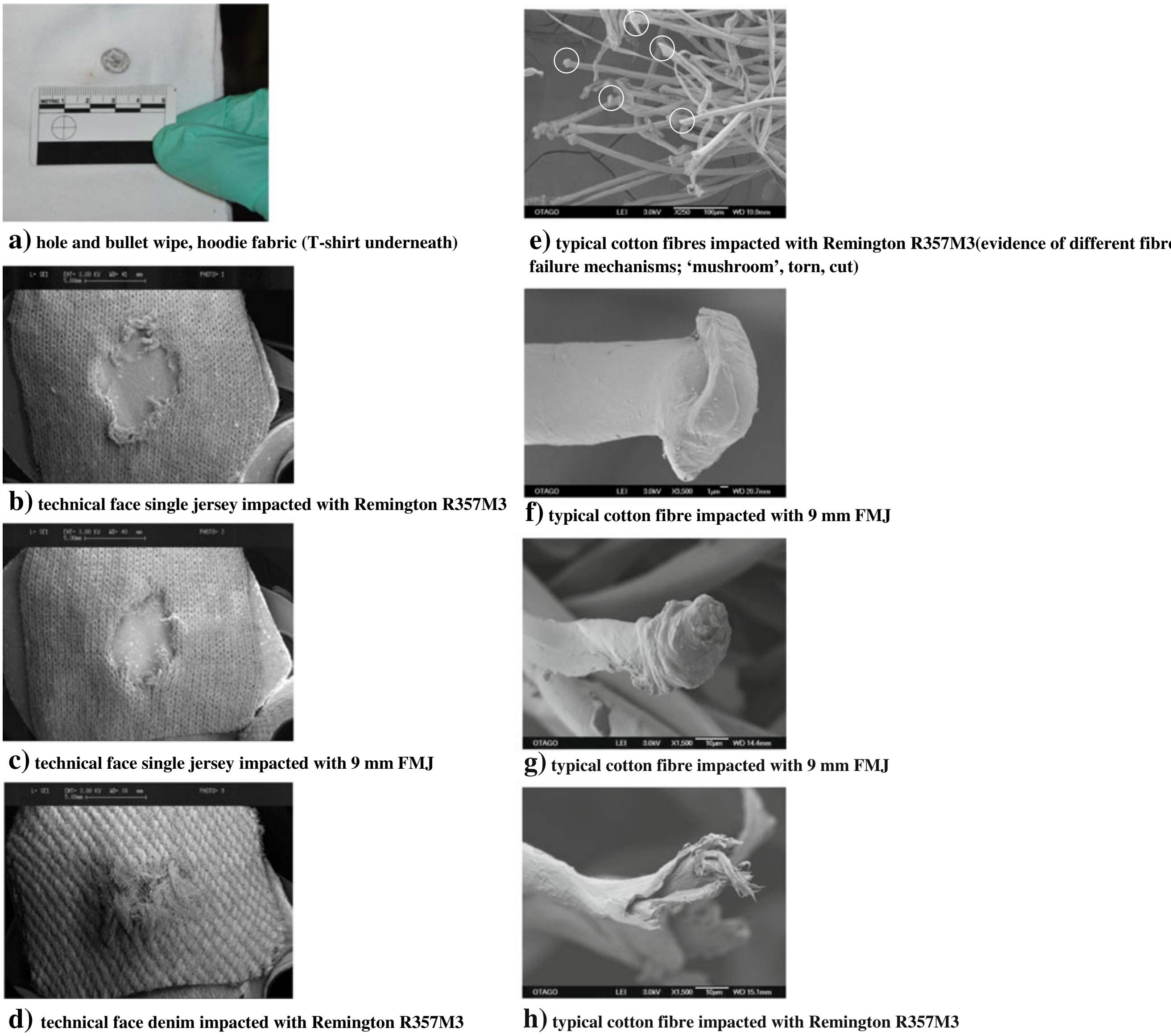


Fig. 5 Fabric damage. **a** Hole and bullet wipe, hoodie fabric (T-shirt underneath). **b** Technical face single jersey impacted with Remington R357M3. **c** Technical face single jersey impacted with 9 mm FMJ. **d** Technical face denim impacted with Remington R357M3. **e** Typical cotton fibres impacted with Remington R357M3 (evidence of different fibre failure mechanisms; 'mushroom', torn, cut). **f** Typical cotton fibre impacted with 9 mm FMJ. **g** Typical cotton fibre impacted with 9 mm FMJ. **h** Typical cotton fibre impacted with Remington R357M3

the wound linear dimension was affected, although weakly, by the face on which it was measured, i.e., the vertical and horizontal dimensions varied between the entry and exit face ($F_{1,\ 96}$=7.44, p≤0.01). On the entry face, both the mean vertical and horizontal dimensions were approximately 5 mm (5.08 mm; 5.78 mm); however, on the exit face the mean vertical dimension was larger than the horizontal dimension (29.05 mm; 25.64 mm), presumably due to the horizontal orientation of the ribs which are harder to penetrate than the intercostal spaces. The entry and exit wound size were affected by the type of fabric covering ($F_{3,\ 96}$= 5.52, p≤0.01). Mean entry holes were similar irrespective of whether or not a fabric covering was present (4.97–6.37 mm); however, exit holes were smaller when a fabric covering was in place (no fabric=32.81 mm; fabric coverings ~23 to 27 mm). Neither the fabric/ammunition, fabric/dimension nor ammunition/dimension interactions were significant ($F_{1,\ 96}$=1.89, p=NS; $F_{3,\ 96}$=1.58, p=NS; $F_{3,\ 96}$=1.08, p=NS).

The mass of bone fragments collected is given in Table 4. Data for the mass of fragmented bone produced during testing was transformed due to inequality of variance ($\log_{10}$). The mean mass of bony fragments collected varied according to the type of ammunition used during testing,

Table 3 Wound dimensions

Thoracic wall specimen	Clothing layer[a]	Shot number	Targeted rib/ total ribs[b]	Ammunition[c]/ velocity (m/s)	Impact site[d]	Entry wound[e]		Exit wound[e]		Wound tract[e]	
						Height (mm)	Width (mm)	Height (mm)	Width (mm)	Length (mm)	Height (mm)
1 (210×340 mm)[f]	None	1	6/10	9 mm/359	5–6	7.0	5.0	18.5	17.0	43.5	7.5
	None	2	3/10	9 mm/360	2–3	7.5	6.0	19.5	14.5	37.0	6.5
	None	3	4/10	9 mm/364	4	7.5	6.5	21.5	16.0	37.0	16.5
2 (240×410 mm)	None	4	4/12	R357/378	4	7.5	6.5	56.0	35.0	36.5	35.0
	None	5	2/12	R357/383	2	6.0	7.5	47.0	47.0	35.0	27.0
	None	6	7/12	R357/385	7	6.0	5.5	36.5	41.0	31.5	18.5
3 (250×400 mm)	None	7	5/11	9 mm/367	5	6.0	5.0	25.0	20.0	46.0	16.0
	None	8	3/11	R357/377	2–3	5.5	7.0	55.0	55.5	42.5	24.5
4 (270×370 mm)	TS	9	3/12	R357/385	3	5.0	6.5	37.0	42.0	40.5	25.0
	TS	10	6/12	9 mm/356	6–7	3.0	4.0	13.0	12.0	40.5	14.0
5 (250×400 mm)	TS	11	6/10	R357/381	5–6	5.5	8.0	25.5	36.5	39.5	18.5
	TS	12	3/10	9 mm/353	3	5.0	5.5	14.5	14.0	39.0	10.5
6 (220×390 mm)	TS	13	6/11	9 mm/355	6	4.9	4.5	17.5	14.5	39.0	10.5
	TS	14	3/11	R357/387	3	4.5	5.5	38.5	32.0	41.5	28.5
7 (250×330 mm)	TS	15	2/10	9 mm/361	2	4.0	5.5	8.5	7.5	40.5	19.5
	TS	16	4/10	R357/390	4	4.0	6.5	23.0	31.0	36.5	18.5
8 (250×400 mm)	TSH	17	4/12	R357/373	4	5.0	6.0	39.5	38.5	45.0	36.0
	TSH	18	7/12	9 mm/366	7	3.5	6.5	25.0	20.5	49.0	12.0
9 (250×380 mm)	TSH	19	5/11	R357/382	5	5.0	6.0	31.5	25.0	47.0	21.5
	TSH	20	3/11	9 mm/357	3	5.5	6.5	16.0	13.5	53.5	17.0
10 (200×390 mm)	TSH	21	6/11	9 mm/358	6	4.5	4.0	15.0	8.5	45.0	15.0
	TSH	22	2/11	R357/386	2	5.0	6.0	41.0	44.5	48.0	33.0
11 (230×420 mm)	TSH	23	2/12	9 mm/363	2	5.0	4.0	20.5	12.0	43.0	9.0
	TSH	24	5/12	R357/383	4–5	5.5	6.0	50.0	24.0	47.5	21.0
12 (230×420 mm)	TSD	25	3/12	R357/383	3	5.5	6.5	41.5	37.0	49.0	21.5
	TSD	26	5/12	9 mm/356	5	4.0	4.5	25.0	14.5	49.0	14.0
13 (250×360 mm)	TSD	27	6/11	R357/384	6	3.5	5.5	36.0	33.5	47.0	19.0
	TSD	28	4/11	9 mm/357	4	3.5	6.0	28.5	9.0	51.0	12.5
14 (220×380 mm)	TSD	29	5/12	9 mm/365	5	4.0	5.0	15.0	9.5	52.0	15.0
	TSD	30	3/12	R357/386	3	5.0	5.5	37.0	44.0	55.0	37.0
15 (240×390 mm)	TSD	31	2/11	9 mm/369	2–3	4.0	5.0	16.0	15.0	53.0	4.0
	TSD	32	5/11	R357/387	4–5	5.0	7.0	35.5	36.0	47.5	19.0

[a] *TS* T-shirt, *TSH* T-shirt+hoodie, *TSD* T-shirt+denim

[b] Thoracic specimens were prepared by cutting through the intercostal space between ribs 3 and 4. 'Targeted rib' and 'total ribs' in this study refer to the number of the rib in the specimen, i.e., the first rib in any thoracic specimen used was labelled rib 1

[c] *9 mm* 9×19 mm FMJ, *R357* Remington R357M3

[d] Shot did not always hit targeted rib; therefore, impact site is described as (1) impacted rib (see footnote a) (e.g., 6) or (2) intercostal space (e.g., between ribs 3 and 4=3–4

[e] Maximum dimension, precision ±0.5 mm

[f] Maximum width and length of thoracic wall specimen

although weakly so ($F_{1, 96}$=4.69, $p \leq 0.50$); more bone fragments occurred due to testing with Remington R357M3 compared to 9 mm FMJ ammunition (~0.38 g; ~0.21 g). Neither fabric coverings nor the origin of the bone fragments (i.e., ejected or in the wound) affected the mass of the bony fragments produced ($F_{3, 26}$=2.44, p=NS; $F_{1, 26}$=0.95, p=NS).

Minimal evidence of fibre/fabric debris either on the skin surface or in the wound was collected (Table 4). Fibre/fabric debris was observed for thicker specimens,

Table 4 Debris

Shot number	Ejected bone (g)[a]	Bone in wound tract (g)[b]	Fibre embedded in skin	Fibre in wound tract
1	–	–		
2	–	–		
3	–	–		
4	0.9286	0.2265		
5	0.3362	0.2272		
6	0.0881	0.5879		
7	0.2951	0.3684		
8	0.1577	–		
9	1.0121	1.3699		
10	0.0939	0.9408		
11	0.2703	–		
12	0.0350	0.0734		
13	0.1215	0.4038		
14	–	0.4880		
15	0.0190	0.3502		
16	–	0.2906		
17	0.1723	0.0768	✓	✓
18	–	0.0289		
19	–	0.3689		
20	0.0454	–		
21	–	0.1210		
22	0.6911	0.1318		✓
23	–	0.0574		✓
24	0.2048	–		
25	0.2181	–	✓	✓
26	–	0.1819	✓	✓
27	0.5161	0.2837	✓	✓
28	0.2265	0.3127	✓	✓
29	–	0.2041		✓
30	0.3419	0.2403	✓	✓
31	0.0172	–	✓	✓
32	0.0436	0.0366	✓	✓

– Nothing collected

[a]Bone fragments collected in range after impact, i.e., ejected from rear of thoracic specimens

[b]Bone fragments retrieved during dissection of wound tract

but particularly for stiffer specimens (single jersey plus denim). No evidence of fibre debris was observed for specimens covered by a thin single jersey fabric. A typical fabric plug recovered from the wound tract is shown in Fig. 6. That minimal evidence of fibre debris or fabric plugs was observed was surprising given the literature which suggested such debris was common place. It may be that only thicker and stiffer layers of fabric can survive the impact event. It should be noted that historical records of fabric plugs, in particular, probably involved fabrics manufactured from animal fibres (i.e., wool, silk) which do not burn; cotton, which was used in the current work, burns. It may also be that the single jersey fabric was simply not strong enough to survive the impact event.

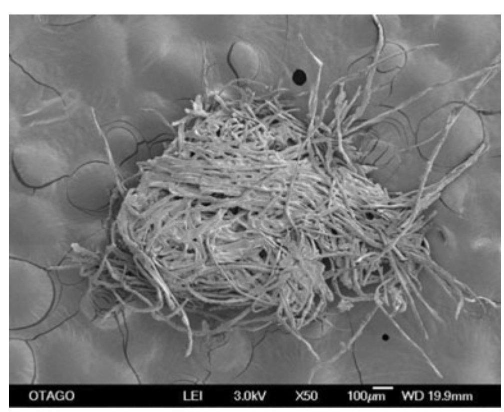


Fig. 6 Typical fabric plug recovered from the wound tract, note compressed fibres (denim impacted with a 9 mm FMJ)

Conclusions

That the Remington R357M3 ammunition was more vulnerable to fragmentation was not surprising given the bullet construction (i.e., an exposed core) and is of interest to both medical personnel operating on a shooting victim and to forensic practitioners from an evidential perspective.

The literature generally describes the damage caused to fabric layer by gunshot as being stellate and that individual fibres mushroom. In the current work, this was not always the case. Clear holes were only observed in thin fabrics (T-shirt). Stellate damage was more commonly observed when Remington R357M3 rounds impacted fabric, and fibre damage was less likely to be identifiable as mushrooming. In comparison, 9 mm FMJ rounds were more likely to punch through the fabric layers, and individual fibres were more likely to be mushroomed in appearance. This is of interest to the forensic community as it might provide some guidance regarding the cause of damage to a fabric layer, although caution is required due to the limited amount of fabrics and ammunition used in this work.

The size of the entry wound was similar for both types of ammunition and this work suggests that measuring an entry wound cannot be used to confidently predict the ammunition involved. Entry wounds were smaller than the diameter of the bullet that caused them. However, there was a difference in the exit wound, Remington R357M3 ammunition resulted in a much larger wound due to the bullet construction which mushroomed and hence a larger surface area was involved in the wounding event. Thus, any information regarding ammunition used that can be provided to medical personnel treating victims of shooting events may be critical.

That fabric coverings did not affect the amount of bony debris produced is interesting, particularly as there was some evidence that apparel layers affected the size of the wound. Recent work has suggested that denim (representative of jeans) can exacerbate wounding caused by high-velocity bullet impacts to the thigh when the bullet does not impact the femur [39]. That more bony debris was caused by Remington R357M3 rather than 9 mm FMJ ammunition was not surprising given the relative constructions of these two bullets, and is of interest to medical practitioners.

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