Journal Pre-proofs

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PII: S1355-0306(19)30092-9
DOI: https://doi.org/10.1016/j.scijus.2019.09.006
Reference: SCIJUS 846

To appear in: *Science & Justice*

Received Date: 30 April 2019
Revised Date: 4 September 2019
Accepted Date: 22 September 2019

Please cite this article as: J. Newton, A. Savage, N. Coupar, J. Fraser, Investigation into the use of CT scanning on impact damage to fabric, tissue and bone caused by both round and flat nosed bullets, *Science & Justice* (2019), doi: https://doi.org/10.1016/j.scijus.2019.09.006

Investigation into the use of CT scanning on impact damage to fabric, tissue and bone caused by both round and flat nosed bullets

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DISCLOSURE STATEMENT

Conflicts of interest: none. All authors approve this article.

Preliminary investigation into the use of Micro-CT scanning on impact damage to fabric, tissue and bone caused by both round and flat nosed bullets

Abstract

Firearm offences in the UK, though not as high as in the USA, are increasing year upon year within both countries (Office for National Statistics, 2018 & Mervosh, 2018). This preliminary study looked into using Micro-CT scanning as a method to visualise impact damage and spray patterns caused by 12 test firings of both round and flat nosed bullets to porcine bone (shoulder and leg) suspended in ballistic gelatine and left with no covering, covered with a skin substitute, or covered with fabric (cotton or denim). Micro-CT scanning alongside VG Studio Max showed that overall, in the case of the shoulder bones the round nosed produced longer spray patterns (35.37 mm) within the gelatine blocks compared to the flat nosed bullet (27.33 mm); while with the leg bones the spray patterns were shorter, round nosed bullet (15.64 mm) and the flat nosed bullet (20.78 mm). These initial results showed that both bullet types produced considerable damage, from splitting to full penetration, which in turn illustrates how Micro-CT scanning has benefits within forensic ballistics, which should be further investigated.

1. Introduction

1.1 Firearms and the 0.22 calibre rifle

The UK has some of the toughest gun laws and with this comes a lower crime rate involving firearms, although it does not completely abolish offences. In 2017 UK police forces, in England and Wales, reported 31 fatalities and a total of 9,578 offences where firearms were involved, which was an increase of 14% from the previous year. Though the number of offences had dropped every year for a 10 year period (2004: 24,070 to 2014: 7,729), the number of offences have increased for the past 3 years from 7,865 to the current 9,578; illustrating that firearm use and ownership may be on the increase [1]. Legally obtaining a firearm licence in the UK is carried out by the local police force under the Firearms Acts 1968-1997 [2-3] and statistics released by the Home Office [4] show an increase of 3% from the previous year, the highest number seen in England and Wales since 1988: 154,958 firearms certificates, to cover 577,547 firearms. Comparing these statistics to countries, such as the USA where guns laws are not as strict; these statistics are but a fraction in comparison, for example in 2017 the USA had 39,773 fatalities [5].

This study focuses on the 0.22 calibre rifle due to the weapon's popularity as a weapon for precision target shooting and pest control, but also one capable of causing damage when used against a person. These weapons in the USA have been used to commit offences as they are easy to obtain due to being low calibre: use 40 gr bullets, have a muzzle velocity of 1145 ft/s, achieve a maximum range of 1500 yards, with an initial velocity of 1257 ft/s dropping to a terminal velocity of only 197 ft/s [6]. The ammunition available today for 0.22 rifles comes in a variety of different styles as well as composition; this study compared two different Eley made bullets, the Match and Club [7-8], to determine how their different shape would be reflected in the impact damage and spray patterns. The Club round nosed bullet is recommended for beginners within the sport of precision shooting in shooting clubs [7], while the flat nose Match bullet is used worldwide by elite shooters within competitions as it is good in both performance, accuracy and produces consistent internal ballistics [8]. Both bullets were identical in weight, height, velocity and energy, with the only difference being the shape of the bullet tip (Fig 1a).

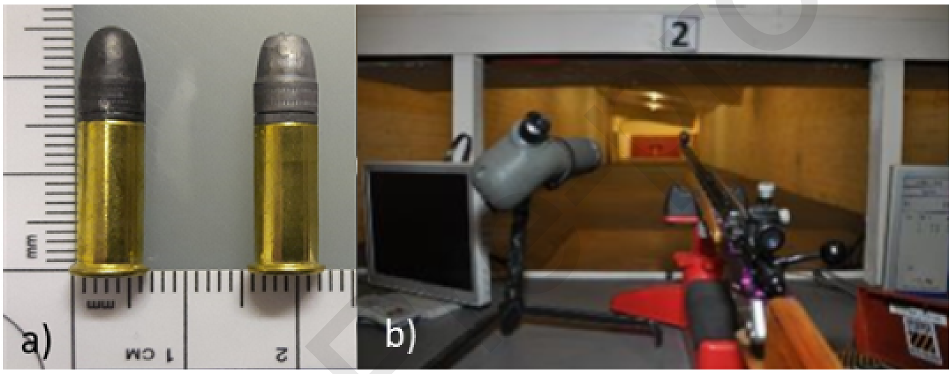

Fig 1: a) Eley Club round nose bullet (left) and Eley Match flat nose bullet (right) and b): 0.22 Calibre rifle set-up with forward view of range shooting set-up.

1.2 Bones, Fabrics and Skin Substitutes

When it comes to the impact of bullets on tissues, muscle and bones most research within the field of ballistics use porcine samples as they are easy to obtain and the bone and skin have similar properties to that of humans. As most injuries from firearms offences usually occur to either to the chest, leg or the head area [9] leg and shoulder bones were used in this study to recreate a real-life firearm offence situation, as well as commonly worn fabrics (cotton T-shirts and denim jeans) and a skin substitute (tyre inner tube) to cover the widely used gelatine human tissue/muscle substitute. A 10% concentration of the gelatine was used in this study as this is commonly associated with the human tissue strength [10].

1.3 Micro-CT scanner

The Micro-CT scanner produces 3D images in a non-destructive and non-invasive manner, allowing the determination of the internal structure and different densities of an item before it was opened; such as in the Cecchetto *et al*. [11] study to determine the distance at which a firearm was discharged by the presence of GSR present at entrance wounds. The review by Rutty *et al.* [12] cites a study by Thali *et al.* [13] reporting the ability of Micro-CT scanning to determine class and individual tool marks that may have been left on bones, following dismemberment. Thus determination of the tool profile used helped assign a suspect weapon to a recovered tip which broke off during an offence. Two more recent studies detailed the use of Micro-CT scanning in the determination of different blades on human bones. The first by Pellettia *et al*. [14] using four different hand saws to determine which saw had caused the different marks on the bones, while the second study by Norman *et al.* [15] used a mixture of power saws, hand powered saws, and knives, to leave marks on long bones. All these studies illustrate the usefulness of Micro-CT scanning as a tool in the investigation and identification of bone damage caused by different tools and weapons.

1.4 Wounds caused by 0.22 calibre rifles

Much of ballistic research commonly focuses mainly on wound patterns, specifically, entry and exit wounds unique to each calibre of weapon. However, with bone Di Maio and Vincent [9] found that the velocity of 250 ft/s was required to penetrate a bone 4-6 mm thick; 350 ft/s for bones 7-9 mm thick and bones ≥10 mm no perforation occurred even with velocities of around 460 ft/s. This suggests that the bones used in this study would require a velocity above 500 ft/s in order to perforate or fully penetrate. Statistics like these should however only be taken in context as each individual bone varies and may contain potential deformities which could affect the overall strength of the bone. Injuries to bone can cause fragmentation and produces temporary cavities, into which the fragments can be dragged forwards or backwards depending upon the bullet and its velocity. These fragments can cause secondary and/or fatal injuries [16], which can often give a pathologist information regarding distance at which a shot was fired.

The majority of ballistic research tends to focus on the difference between the calibre rather than the difference between bullets. Wightman, Beard and Allison [17] looked into the difference between types of air rifle pellets and how they interacted with bone, then in 2015, Wightman, Wark and Thomson [18], investigated the interaction between air rifle pellets and clothing. This study aims to combine these two studies and determine the impact damage to bone by both round and flat nosed bullets and whether the introduction of fabrics, as well as a skin substitute, will have any effect on the penetration depth.

2. Materials and Method

2.1 Two Litre Gelatine Block Preparation

Two lots of 100 g of Fluka (270-310G bloom strength, Porcine) gelatine was added individually to 900 mL of cold water in 1000 mL beakers. The solution was continuously stirred for 3 minutes and then placed into the water bath (Grant Sub 14; pre-heated to a temperature of 37 ℃). After 20 minutes the beakers were stirred for a further 3 minutes, this was then repeated a further three times (time intervals: 40, 60, 80 minutes), then at 90 minutes a drop of cinnamon oil was added to each beaker, and each stirred again for 3 minutes [17-20]. At this point, if the gelatine was clear, it was poured into the pre-prepared 2 L moulds. While the gelatine was still liquid, the bones (Porcine, leg and shoulder) were suspended within the gelatine by the use of string secured by tape to the outside of the mould.

2.2 Photography

Each bone was photographed using a Nikon D5300 with a Nikon AF-P and Nikkor 18-55 mm 1:3.5 – 5.6G lens before and after being placed in the gelatine, after each bullet was fired and finally once all the gelatine was removed, after Micro-CT scanning. Settings were dependent on the sample being photographed and whether or not it was in the gelatine.

2.3 Micro-CT scanner

Each of the bones were scanned, using a Nikon Metrology X-TEK HMX 225, before being placed into ballistic gelatine in order to obtain a detailed image of each of the bones internal structure, such as any damage or deformities. The bones were then scanned again after being shot, both in the gelatine and after the gelatine was removed, to obtain a better detailed image as to the internal and external damage caused by each of the bullets. The voltage (kV), current (μA), filter and projections used was dependent on each bone and its density [Appendix 1].

2.4 Rifle Range

Fig 1b is a representation of the set-up used at the rifle range, showing forward view with the same rifle (0.22 Calibre Rifle, Anschutz 1813 Match 54) used consistently throughout the project.

The bones situated within the gelatine were placed upon a wooden table at the end of the range (distance of 25 yards) with a shooting target covering them to allow a target area of the bones for the shooter from the shooting point. This was carried out for both the uncovered blocks and those covered with fabric or the skin substitute, which were pinned into place. Each experiment was carried out three times.

2.5 Statistical Analysis

Data were analysed in SPSS v25 using a 2 way ANOVA (General Linear Model). Each experiment focused on a different bullet type and investigated the effects of two factors, the target bone used and the type of fabric covering. The dependent variable was the mean distance of debris form the centre of the site of impact of the bullet. Parametric assumptions of the two-way ANOVA were tested.

3. Results and Discussion

3.1 Penetration of the Eley Match and Club bullets

A plain gelatine control block was shot first in order to determine the penetration depth of the bullets without a cover and for both the Eley Match and Club bullets, and both bullet types penetrated straight through. Full penetration was also the case with both the Eley Match and Club ammunition for the shoulder bone as well as the leg bone.

3.2 Impact damage to shoulder bones

Table 1: Shoulder bone results for bone with no covering, cotton, denim or skin substitute (tyre inner tube). Distance measured from the start of the bone to the visible end of the spray pattern observed on the micro-CT image (using VG Studio Max 3.0).

Shoulder Bone Number	Bullet type	Covering	Distance of spray pattern (mm)
S1	Round	None	28.77
	Flat		42.77
S2	Round	Cotton	17.31
	Flat		16.73
S3	Round	Cotton	20.48
	Flat		22.14
S4	Round	None	39.59
	Flat		42.95
S5	Round	Skin substitute	8.34
	Flat		12.48
S6	Round	Denim	29.04
	Flat		28.67
S7	Round	None	35.37
	Flat		27.33
S8	Round	Skin substitute	45.28
	Flat		43.03
S9	Round	Denim	46.77
	Flat		52.15
S10	Round	Skin substitute	26.91
	Flat		35.87
S11	Round	Cotton	13.29
	Flat		47.18
S12	Round	Denim	43.06

	Flat		43.04

The round nosed bullet produced spray patterns ranging from 46.77mm to 8.34mm (38.43mm difference), while for the flat nosed bullet they ranged from 52.15mm to 12.48mm (39.67mm difference); a difference of just 1.24mm between the two bullet types. Though the difference between the two bullets was small, previous research with air rifle pellets, showed the pointed pellets were penetrating "up to 50% further" [17] than the round pellets, and there was a bigger difference between the distances travelled by the air pellets. Due to the more aerodynamic shape of the round nosed bullet, it was expected that these bullets would travel further than the flat nose bullet.

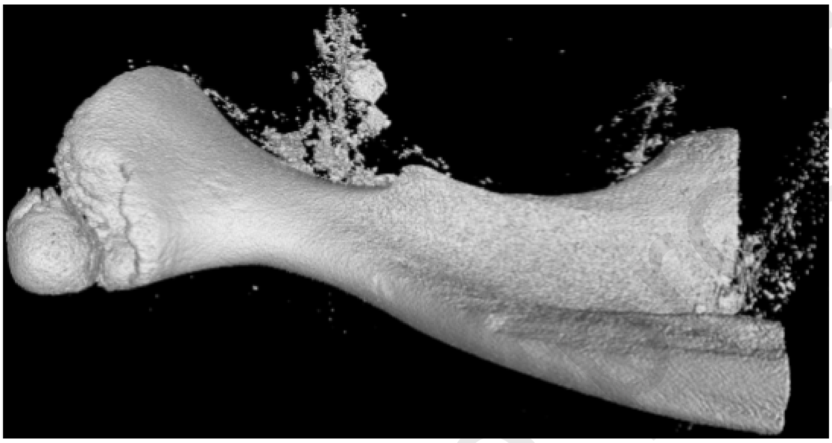

Fig 2: Shoulder bone in plain gelatine and no covering, showing spray patterns after being shot flat nosed bullet (left) and round nosed bullet (right).

Fig 2 shows the bone damage and spray patterns of the two different bullet types in non-covered gelatine and shows the patterns are quite different for the two bullets. The round nosed bullet created a spray of 35.37 mm, while the flat nosed bullet created a spray of 28.33 mm. One of the main differences was that the round nosed bullet spray seems to be mainly that of the bone marrow while the flat nosed bullet seems to have dragged some of the bone into the cavity that was created. These larger fragments could cause potential secondary injuries and when the gelatine was completely removed it was observed there was a fracture running the full length of the bone with only the surrounding tissue and muscle keeping the bone together, with the exit wounds clearly visible (Fig 3). When a surgeon was asked their opinion, they stated that this was insufficient damage to require surgery, as it was risky to operate due to the amount of muscle and tissue that surround the shoulder bone, however, if encountered as a chest injury this would be an emergency case [21].

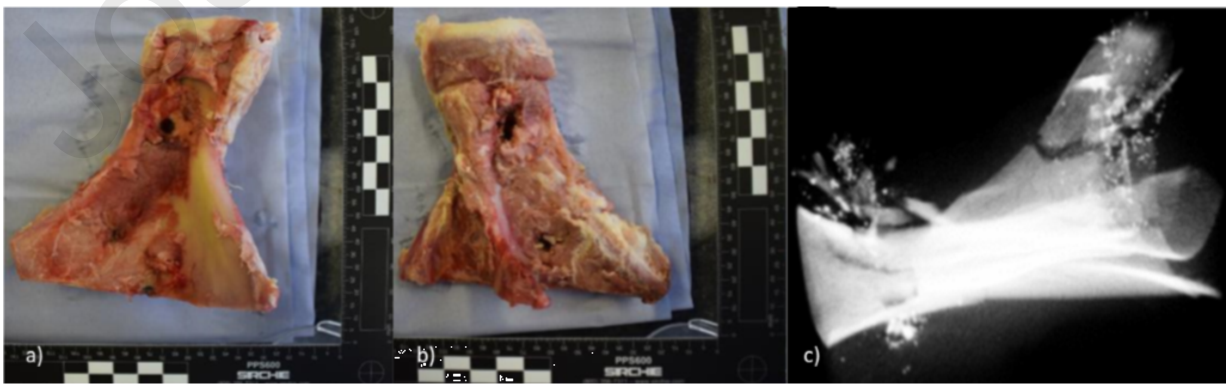

Fig 3: a) Shoulder bone entry wound, b) Shoulder bone exit wound (top flat nose and bottom round nose) and c) Shoulder bone (Micro-CT scan) after being shot (x-ray), round nose (right) and flat nose (left).

Fig 3a illustrates the differences in the entry wounds of the two bullets, with the flat nosed wounds leaving an almost perfect 'hole punched' entry (~7 mm) whereas the round nose created an entry wound so small it can barely be seen (~4 mm). However, the reverse of the bone (Fig 3b) showed a different story with the flat nose bullet creating a rather noticeable hole in the bone (~12 mm) whereas the round nosed bullet left what appears to be a much smaller small hole (~5 mm) that was barely visible due to the surrounding tissue. The shoulder bone with a cotton covering showed a dramatic difference in the spray pattern and damage to the bone (Fig 3c). Even with a covering of cotton, the damage to the bone was considerable, and it had been expected that the fabric would provide some protection to the bone by reducing the impact velocity. However, this was not the case the flat nosed bullet appears to have caused a fracture along the top of the bone, and from the bullet exit, spreading to the rest of the bone. This resulted in bone fragments creating a cavity after they had been dragged through due to the velocity of the bullets. Though penetration was not reduced the spray patterns were shorter when compared to non-covered blocks with the round producing a spray of 17.31 mm and the flat producing a spray of 16.73 mm. The spray pattern caused by the round nosed contained more bone marrow, whereas the flat nosed bullet caused more bone fragmentation. Previous research does not comment on bone marrow spray, therefore there is currently no data to state whether this is a common occurrence within firearm injuries, although as the bullet tears through the bone it would be expected to affect the marrow within the centre of the bone.

The denim covered blocks showed impact damage similar to that observed with the cotton covering, including bone marrow being sent forwards upon impact with the bullet. The spray pattern caused by both the round (29.04 mm) and flat nosed (28.67 mm) bullets, showed an increase from the cotton covering but still less than without a covering. What was more noticeable with this shoulder bone compared to the other bones was that the flat nosed bullet, in this case, did not appear to spray large bone fragments but instead a lot of smaller fragments, while the round nosed continue to spray mainly the bone marrow.

Previous research has shown that the addition of clothing reduces the penetration depth of bullets [17]; however, in the case of this study, it also showed a decrease in the spray pattern. Overall, the denim showed a decrease of 6.33 mm in spray pattern with the round nosed but an increase of 1.34 mm with the flat nose. This is surprising as generally the flat nosed was producing longer spray patterns compared to round nosed bullets. However, this could be explained by where the bone was stuck, as with the shoulder bone the flat nosed bullet was fired directly through the T-junction, which could have affected the results obtained. As the bullet did not travel directly through the bone but rather at an angle and clipped the edge, on exiting, potentially causing more damage than it would have if it was fired straight through the bone, leading to the unexpected results.

The last of the coverings used was the skin substitute (tyre inner tube), and it was believed this would potentially stop the bullet and reduce the impact damage caused to the shoulder bones, but this was not the case. The round nosed bullet going through the bone produced a spray of 45.28 mm, which is an increase of 9.91 mm compared to the shoulder bone with no covering. This is significant as research by Warlow [16] suggested that a skin substitute would decrease the penetration depth or in the case of this study decrease the spray pattern, but instead, here it has increased. The flat nosed bullet hit the side of the bone, producing a spray pattern of 43.03 mm which was also an increase of 15.70 mm in the length of spray. While each of the coverings were tested three times, the skin substitute produced the greatest difference in results (Table 1), with an average spray of 26.84 mm with the round nosed bullet and 30.46mm with the flat nosed bullet.

Overall, the shoulder bone shot at with the various coverings (cotton, denim and skin substitute) showed a large spray pattern of varying lengths with each of the bullets. It could be said with a shoulder bone that the flat nosed bullet is producing slightly more damage to the bones than the round nosed bullet.

3.3 Impact damage to leg bones

Table 2: Leg bone results for bone with no covering, cotton, denim or skin substitute (tyre inner tube). Distance measured from the start of the bone to the visible end of the spray pattern observed on the micro-CT image (using VG Studio Max 3.0).

Leg Bone Number	Bullet type	Covering	Distance of spray pattern (mm)
L1	Round	Skin substitute	22.12
	Flat		22.50
L3	Round	None	29.34
	Flat		33.88
L4	Round	Denim	12.35
	Flat		20.26
L5	Round	Cotton	0
	Flat		20.31
L6	Round	Cotton	16.17
	Flat		29.50
L7	Round	None	18.27
	Flat		17.06
L8	Round	None	21.82
	Flat		18.56
L9	Round	Denim	32.71
	Flat		19.17
L10	Round	Denim	3.23
	Flat		0
L11	Round	Cotton	11.27
	Flat		14.12
L12	Round	Skin substitute	32.15
	Flat		34.21
L13	Round	Skin substitute	54.86
	Flat		8.72

Leg bones varied in density and shape compared to the shoulder bones and the overall leg bone results varied greatly (Table 2); the round nosed bullet ranged from 0.00 mm to 54.86 mm, and the flat nosed bullet spray pattern ranged from 0.00 mm to 34.21 mm, with the longest spray pattern differing by 20.65mm. The leg bones also appeared to have a greater areas of visual damage caused to them and that some of the longer spray patterns were due to bone marrow travelling a distance within the gelatine. Looking firstly at a leg bone with no coverings (Fig 4) it was observed that already the spray pattern produced by the two bullets were slightly less when compared to the shoulder bones, by 6.03 mm than the spray pattern of the shoulder bone, while the flat nosed bullet was 6.55 mm more than the shoulder bone, but the area of damage was much greater.

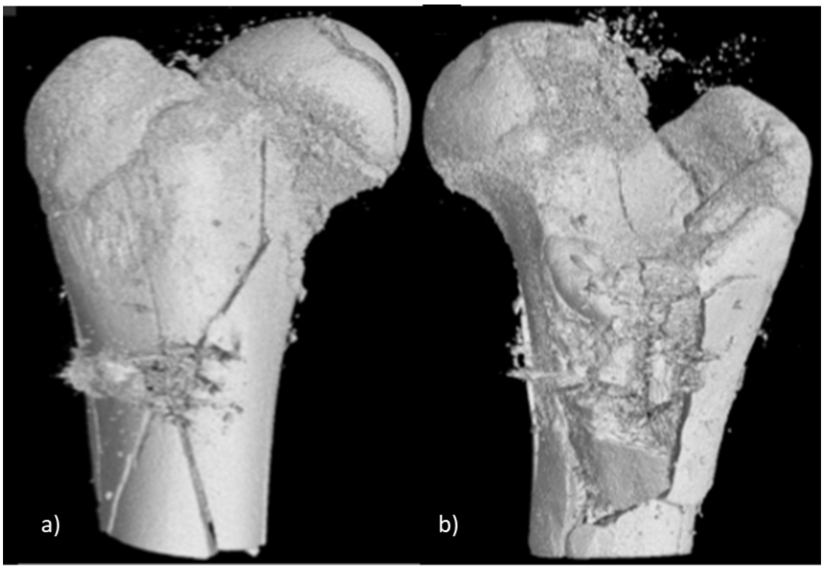

Fig 4: Leg bone after being shot a) entry wound and b) exit wound.

This seems to show that the flat nosed bullet has more impact on the leg bones compared to the shoulder bones. Which could be down to the difference in density between the two bones as well as the leg bone being round compared to the shoulder bone, which is flat and wider hence causing more damage. Also, the flat nosed bullet was fired into the main area of the bone while the round nosed bullet was fired into the ball area of the leg bone, if it had been fired at the main area of the leg bone a different spray pattern may have been witnessed and vice versa with the flat nosed bullet. It was also observed that the flat nosed bullet pulled more bone fragments into the cavity it created compared to the round nose bullet from the exit wounds on the leg bones compared to the shoulder bones. The damage from the flat nosed bullet exit wound (Fig 4b) was wider spread, with visible fragments of bone missing, while the round nosed bullet exit wound was hardly visible. While micro-CT scanning the bone, it was thought that once the gelatine was removed that the bone would fall apart, but this only occurred during disposal and that for a while the bone fragments were held in place by the muscle and tissue surrounding it.

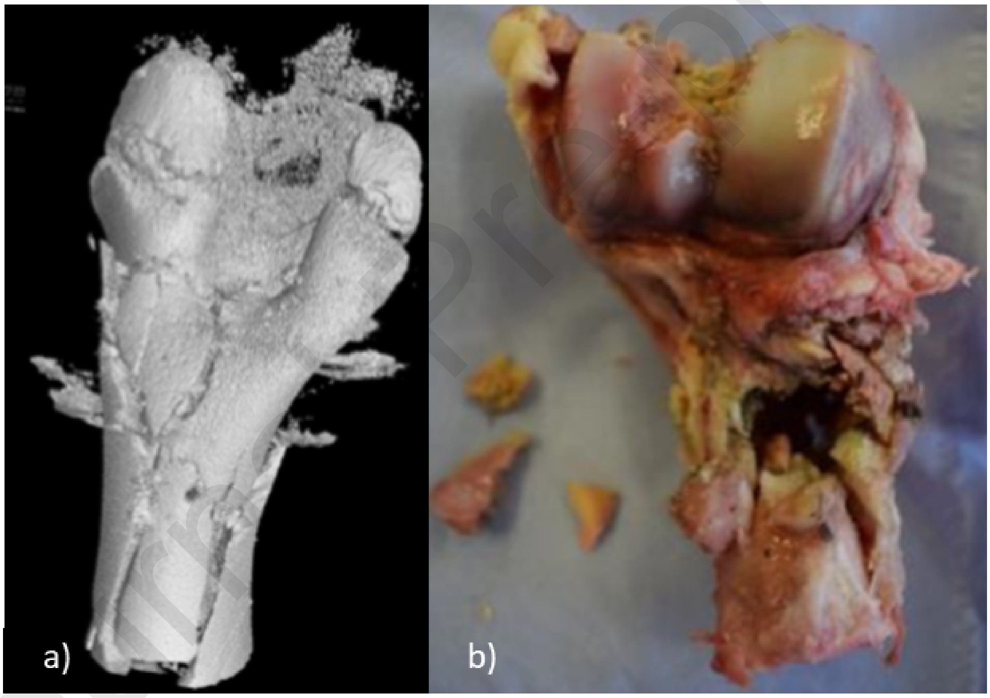

Fig 5: a) Leg bone after being shot and (b) Leg bone out of gelatine, illustrating the disintegration effects of the bullet on the bone structure.

With a cotton covering the impact damage to the leg bone (Fig 5) was much greater in comparison to the cotton covered shoulder bone. In this case, the round nose bullet was fired at the top of the bone producing a spray pattern of 11.27 mm, while the flat nosed bullet was fired into the main area of the bone caused a spray pattern of 14.12 mm. The flat nosed bullet created subsequent fractures all along the bone, and it appears to have almost split the bone in half. This has the potential to inflict secondary injuries internally due to the bone fragments being near arteries and veins. The damage caused by the flat nosed bullet's exit, led to small fragments of bone falling out of the bone when being removed from the gelatine. The round nosed bullet exit wound was not as prominent as was originally expected and can only be slightly seen at the top of Fig 5b as is evident with the bone marrow being visual at the joint area. Fig 5b shows that once out of the gelatine parts of the bone fell out, and it was possible to see entirely through the bone, although when looking at the top of the bone the round nosed bullet caused little to no damage. The spray pattern for this bone covered with cotton were smaller than when the leg bones had no covering, which is what was already found in previous research by Wightman, Wark and Thomson [18] using air rifle pellets. The cotton covering reduced the round nosed bullet spray pattern by 18.07 mm, while the flat nosed bullet spray pattern was reduced by 19.76 mm. When covered with denim, a different spray pattern was observed for the round nosed. Up until now the flat nosed bullet produced a wider spread spray compared to the round nosed bullet.

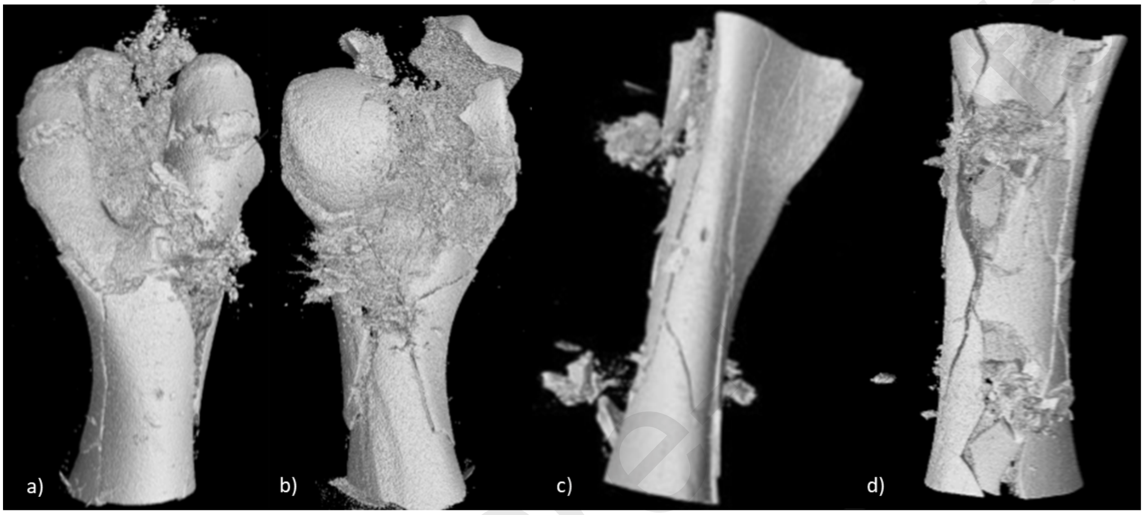

Fig 6: a) Ball end of leg bone after being shot, b) Ball end of leg bone exit wound and mid-sections of leg bone after being shot with c) &d).

Fig 6 shows the damage from the front of the bone, and it appears to have some damage to the side of the bone, but when this bone is viewed from the back (Fig 6b) the damage is wider spread and again produced different results compared to what has already been observed. The round nosed bullet until now had only ever produced a spray pattern based on the bone marrow but with this bone, it fragmented, and subsequently produced a spray pattern of 32.71 mm, which was one of the largest spray patterns seen with the leg bones. The flat nosed bullet produced a smaller spray pattern of only 19.17 mm, but the flat nosed bullet seemed to have fractured the bone more than the round nosed bullet. This is one of the few times in which the round nosed produced a larger spray pattern in comparison to the flat nosed bullet.

The final covering used on the leg bone was the skin substitute which again produced large exit spray patterns with this bone both of the bullets spray patterns were almost identical: round nosed, 22.12 mm and flat nosed, 22.50 mm. Fig 6c & d show that this bone was almost completely destroyed after both of the bullets were fired at the leg bone, with the impact damage appearing to have resulted in more fractures occurring outside of the initial impact area. However, even with this amount of damage, the bone remained relatively intact until completely removed from the gelatine, with many fragments of the bone remaining in the gelatine. The bullets did not show much difference in spray patterns compared to what was seen previously in this study. However, this bone reacted differently, which may be due to it having been kept for a longer period than the other bones in the study and that it was the main section of the bone with no joints attached. This may have impacted the overall density of the bone causing the bone to be weaker.

Again with the leg bone, the skin substitute did not reduce the penetration or spray pattern caused by the two bullets. Instead, the spray patterns observed with the skin substitute was similar to that of the other coverings (cotton and denim) and no covering. However, there was one leg bone which produced a particularly large spray pattern.

The spray pattern observed at the bottom of the bone was produced by the round nosed bullet and resulted in the longest recorded spray pattern (54.86 mm). This was mainly due to the bullet ricocheting off the bone upon impact causing fragments of bone to spray off. Ricochet only occurred with this bone.

3.3 Overall Comparison

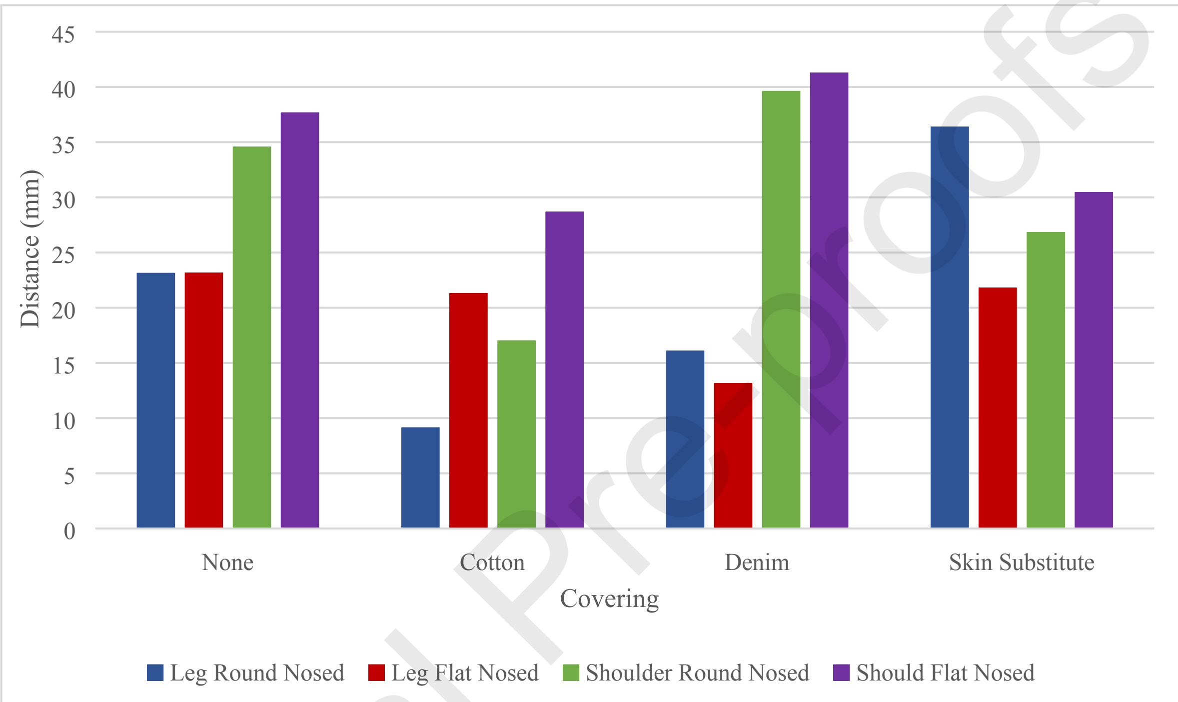

Fig 7: Average spray pattern from results of all bone, bullet, and covering types.

As observed in sections 3.2, 3.3 and Fig 7, the leg and shoulder bones produced very different results. Overall, it was observed that the shoulder bone produced longer spray patterns compared to the leg bones, with the exception of the flat nose on the leg covered by cotton and the round nose on the leg again covered by the skin substitute. With the leg bones also producing wider spread damage with more fractures resulting from the impact of the bullets. The general trend observed in this study was that the clothing reduced the spray pattern overall, but the main contributor to the length of spray were the bones. When it came down to the individual coverings cotton led to the most reduced spray pattern recorded when covering the shoulder bone while it was denim for the leg bone, while the leg and shoulder bones seemed to produce longer sprays with the addition of the skin substitute. This was surprising as it was thought to potentially reduce the velocity of the bullet due to the elastic nature of the tyre inner tube (skin substitute); however, full penetration was observed with both bullets.

3.4 Statistical Analysis

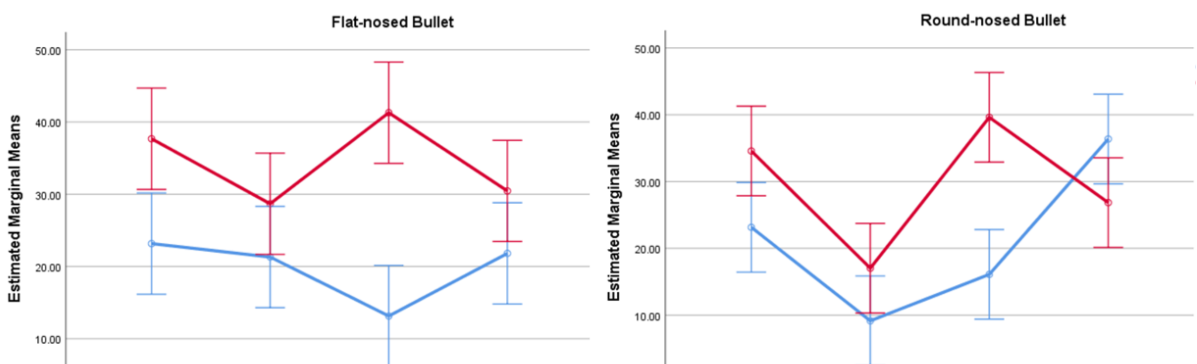

Fig 8 - Distance of debris for leg and shoulder bones shot by (a) flat-nosed bullets (b) round nosed bullets. The bones were either left uncovered (none) or covered by skin, cotton or denim. Each data point is the mean distance of debris from replicate shots on 3 different bones.

Experiment 1. Flat-nosed bullets on Leg and shoulder bones covered by fabric.

Twelve leg bones were divided into four groups of 3 bones, and each group was covered with a different fabric (cotton, denim or skin) or left uncovered (Fig 8a). The bones were shot with flat-nosed bullets, and the distance of debris scatter measured as described in the methods. The process was repeated with twelve different shoulder bones, group and covered with the same fabrics or left uncovered. The data were analysed using a 2-way ANOVA and examined the main effects of the two factors (bone-type and fabric) and also the interaction between bone type and fabric. There was a significant effect of bone type on the scatter of debris from the bone shot by a flat-nosed bullet (F (1, 16) = 8.763; p= 0.009, effect size partial η_p^2 = 0.354, power = 0.794 α =0.05). There was no main effect of fabric (F (3, 16) =0.22; p=0.879) and no interaction between bone type and fabric (F (3,16)=0.920; p =0.454). Overall debris scatter was significantly greater for the shoulder bones compared to leg bones (Mean difference = 14.7mm, S.E. = 5.0mm) 95% CI of mean difference (4.2, 25.2); p = 0.09 (adjusted for multiple comparisons). The estimated marginal mean scatter for leg bone was 19.9 mm (S.E. = 3.5 mm 95% CI (12.4, 27.3) whereas, for the shoulder bone, the estimated marginal mean scatter was 34.5mm (S.E. = 3.5mm CI (27.1, 42.0). Assumptions of the 2-way ANOVA were satisfied, i.e. all measurements were independent of each other, residuals were normally distributed according to the Normal Q-Q plot and histogram of residuals (not shown) (Shapiro Wilks (24) =0.955; p= 0.348 and variance across groups was equal (Levene's test F (7,16) = 0.666; p = 0.698 H0: Variances equal).

Experiment 2. Round-nosed bullets on Leg and shoulder bones covered by fabric.

The procedure for experiment 1 was repeated except that the bones were shot with round-nosed bullets (Fig 8b) but there was no significant main effect of bone type (F(1,16) = 3.078; p=0.098) or fabric type (F(3,16) = 3.081; p=0.57) and no interaction between the factors (F(3,16) = 2.071; p=0.144). All assumptions of the two way ANOVA were satisfied.

Differences in the spread of bone debris from between bone types was depend on the bone used. In Exp one, the flat nose bullet generated more debris spread from shoulder bone compared with the leg bone, but the spread of debris from the two bones was similar when a round-nosed bullet was used. The fabric covering did not influence spread of debris.

It is acknowledged that a small dataset (n=3) was used however, the effect on size and power are large and these could be used to determine a more appropriate sample size for a repeat investigation.

3.5 Retrieved bullet analysis

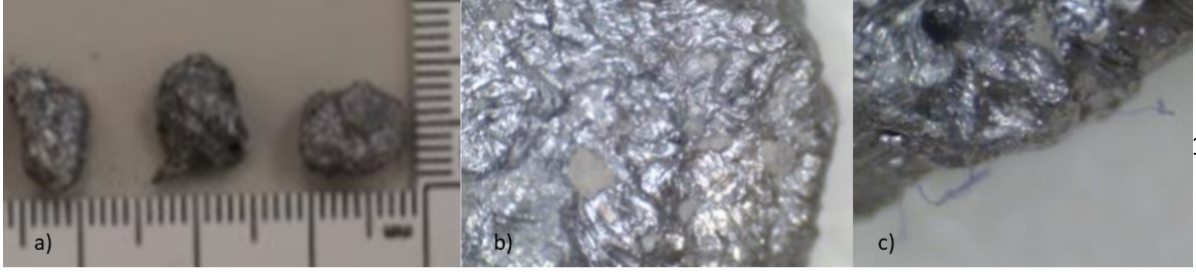

Fig 9: a) Retrieved bullets, b) Close up of retrieved bullet and c) close up of fibre on the bullet.

Fig9a shows some misshapen retrieved bullets that had ruminants of bone and gelatine along with fibres from the denim coverings used (Fig9b & c). These fibres could aid in forensic investigations as they could give an indication of the potential clothing worn by a victim. Additionally, the fibres also have the potential to cause infections in the wounds; this was also noted by Wightman, Wark and Thomson [18].

4. Conclusion

This preliminary study highlighted the damage which these lower calibre weapons can produce and although this study initially set out to investigate penetration depth the spray pattern produced results which had not been reported before (range: no spray pattern to a 54.86 mm spray pattern). This study showed that while the difference in damage between round and flat nosed bullets visually was little at times, internally, the damage was much greater with the flat nosed bullets. Also that the flat nosed bullet caused more damage particularly to more cylindrical shaped leg bones, while the round nosed bullets produced larger cavities and longer spray patterns, in particular with flatter shoulder bone. Finally, while the initial results showed that the bone type did influence the damage caused while the fabric type did not, as illustrated in section 3.4. It also illustrated the novel use of Micro-CT scanning in forensic ballistic examinations as it is a non-evasive technique that provides detailed images of the internal structures as well as wound ballistics. Further trials would need to be carried out to determine the full impact of flat and round nosed bullets on these bone types.

Acknowledgements

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Appendix 1: Scan information for all bones used in the study, including voltage, current and filters used, along with the outcome of the scan.

Key:

- Scan was not very good
- Scan was okay but would probably be better if rescanned
- Scan was great the bone is finished with

Item Code	Sample	Voltage (kV)	Current (µA)	Filter	Projections
H2441	Pig Leg Bone (L6)	115	85	0.5 Cu	300
H2442	Pig Leg Bone (L6)	170	68	0.25 Ag	300
H2443	Pig Leg Bone (L1)	190	78	0.5 Sn	300
H2444	Pig Leg Bone (L1)	102	31	None	300
H2445	Pig Leg Bone (L3)	102	31	0.25 Al	300
H2466	Pig Leg Bone (L1)	102	31	None	500
H2470	Pig Leg Bone (L2)	102	31	None	500
H2471	Pig Leg Bone (L3)	102	31	None	500
H2472	Pig Leg Bone (L4)	102	31	None	500
H2473	Pig Leg Bone (L5)	102	31	None	500
H2474	Pig Leg Bone (L6)	102	31	None	500
H2475	Pig Leg Bone (L7)	102	31	None	500
H2476	Pig Neck Bone (N1)	102	31	None	500
H2490	Pig Neck Bone (N2)	110	35	None	500
H2492	Pig Neck Bone (N2)	90	36	0.1 Al	500
H2493	Pig Neck Bone (N3)	105	40	0.5 Al	500
H2494	Pig Neck Bone (N4)	78	62	None	500
H2495	Pig Shoulder Bone (S1)	70	53	0.1 Al	500

H2496	Pig Shoulder Bone (S2)	70	50	0.25 Al	500
H2497	Pig Shoulder Bone (S3)	76	50	0.25 Al	500
H2500	Pig Shoulder Bone (S3)	76	50	0.25 Al	700
H2503	Pig Neck Bone (N1)	78	62	None	500
H2524	Pig Leg Bone (L3)	80	57	0.25 Al	500
H2525	Pig Leg Bone (L4)	80	57	0.25 Al	500
H2526	Pig Leg Bone (L5)	80	65	None	500
H2527	Pig Leg Bone (L6)	90	53	None	500
H2528	Pig Shoulder Bone (S1)	88	60	0.25 Al	500
H2529	Pig Shoulder Bone (S2)	95	43	0.25 Al	500
H2530	Pig Leg Bone (L3)	95	55	0.1 Al	500
H2531	Pig Shoulder Bone (S2)	95	59	None	500
H2560	Gelatine Tub 6	96	60	None	500
H2563	Gelatine Tub 6	118	60	0.25 Sn	300
H2565	Gelatine Tub 6	150	35	1 Al	500
H2566	Gelatine Tub 6	150	35	1 Al	500
H2568	Gelatine Shoulder (S2)	143	45	1 Cu	500
H2569	Gelatine Shoulder (S3)	100	45	2 Al	500
H2570	Gelatine Shoulder (S2)	90	40	2.5 Al	500
H2571	Gelatine Shoulder (S3)	107	35	2.5 Al	500
H2609			Did Not Scan		
H2611	Gelatine Tub 3	130	50	None	500
H2615	Gelatine Shoulder (S2)	80	110	None	500
H2617	Gelatine Shoulder (S2)	80	110	None	500
H2619	Gelatine Tub 3	80	110	0.5 Al	500
H2620	Gelatine Shoulder (S3)	80	110	0.5 Al	500
H2623	Gelatine Shoulder (S1)	80	110	None	500
H2624	Gelatine Tub 5	80	110	0.5 Al	500
H2625	Gelatine Shoulder (S1)	80	120	1 Al	500
H2626	Gelatine Leg (L3)	80	110	1 Al	500

H2627	Gelatine Leg (L7)	80	110	1 Al	500
H2630	Pig Shoulder Bone (S4)	80	95	1 Al	500
H2631	Pig Shoulder Bone (S5)	80	100	1 Al	500
H2634	Pig Shoulder Bone (S6)	80	95	1 Al	500
H2649	Pig Shoulder Bone (S7)	80	95	1 Al	500
H2651	Pig Leg Bone (L8)	80	90	1 Al	500
H2656	Pig Leg Bone (L9)	80	90	0.5 Al	500
H2657	Pig Leg Bone (L10)	75	91	1 Al	500
H2658	Pig Leg Bone (L11)	70	90	1 Al	500
H2661	Gelatine Shoulder (S1)	75	85	1 Al	500
H2662	Gelatine Shoulder (S3)	75	85	1 Al	500
H2663	Gelatine Shoulder (S2)	75	85	1 Al	500
H2664	Gelatine Leg (L5)	75	85	1 Al	500
H2667	Gelatine Leg (L7)	75	80	1 Al	500
H2672	Pig Shoulder Bone (S8)	75	90	1 Al	500
H2673	Pig Shoulder Bone (S9)	80	90	1 Al	500
H2674	Pig Shoulder Bone (S10)	75	85	1 Al	500
H2675	Pig Shoulder Bone (S11)	75	80	1 Al	500
H2691	Gelatine Tub 3	90	78	1 Al	500
H2692	Gelatine Tub 5	90	78	1 Al	500
H2693	Gelatine Tub 2	90	78	1 Al	500
H2695	Gelatine Tub 6	95	90	1 Al	500
H2696	Gelatine Tub 7	95	85	1.5 Al	500
H2698	Pig Shoulder Bone (S12)	75	85	None	500
H2699	Pig Shoulder Bone (S13)	72	85	None	500
H2701	Gelatine Shoulder (S5)	80	100	1 Al	500
H2702	Gelatine Leg (L9)	80	90	0.5 Al	500
H2703	Gelatine Leg (L10)	75	95	0.5 Al	500
H2704	Gelatine Shoulder (S4)	80	95	1 Al	500
H2705	Gelatine Shoulder (S7)	75	85	0.5 Al	500

H2706	Gelatine Shoulder (S5)	70	80	1 Al	500
H2707	Gelatine Shoulder (S4)	70	85	None	500
H2708	Gelatine Leg (L9)	66	80	1 Al	500
H2709	Gelatine Leg (L10)	75	90	None	500
H2711	Gelatine Leg (L1)	70	85	1 Al	500
H2727	Gelatine Leg (L4)	70	85	1 Al	500
H2728	Gelatine Leg (L11)	75	85	0.5 Al	500
H2732	Gelatine Leg (L8)	75	80	1 Al	500
H2733	Gelatine Leg (L9)	75	85	0.5 Al	500
H2734	Gelatine Leg (L10)	75	85	0.5 Al	500
H2735	Gelatine Leg (L4)	80	85	0.5 Al	500
H2746	Pig Leg Bone (L12)	80	90	0.5 Al	500
H2747	Pig Leg Bone (L13)	80	90	0.5 Al	500
H2748	Pig Leg Bone (L14)	60	65	0.5 Al	500
H2749	Pig Leg Bone (L15)	60	65	0.5 Al	500
H2750	Pig Leg Bone (L16)	70	75	1 Al	500
H2751	Pig Leg Bone (L17)	75	80	1 Al	500
H2777	Gelatine Shoulder (S9)	75	85	1 Al	500
H2781	Gelatine Shoulder (S12)	65	75	1 Al	500
H2782	Gelatine Shoulder (S6)	70	75	1.5 Al	500
H2783	Gelatine Shoulder (S13)	Did Not Scan, error message occurred as well as the max			
H2785	Gelatine Shoulder (S13)	80	85	1 Al	500
H2789	Gelatine Shoulder (S8)	80	85	1 Al	500
H2790	Gelatine Shoulder (S10)	80	85	1 Al	500
H2791	Gelatine Leg (L13)	80	85	1 Al	500
H2792	Gelatine Leg (L12)	80	85	1 Al	500
H2793	20% Gelatine Leg (L16)	80	85	None	500
H2794	20% Gelatine Leg (L17)	80	85	1 Al	500
H2795	20% Gelatine Shoulder (S11)	80	85	1 Al	500

Highlights

- Penetration capability of .22 bullets into soft tissue and bone through clothing.
- Non-covered and covered gelatine blocks with and without bones to simulate a human.
- Different bullets used: Round nosed and flat nosed.
- CT scanning visualisation of internal and external damage caused by bullets.
- Level of damage caused to fabric, tissue and bone was affected by bullet type used.

Acknowledgements

The authors would like to thank Dr. Keith Sturrock for providing on and maintaining the Micro-CT scanner, which was essential to this study as well as the continued guidance on this throughout the study.

The authors would also like to thank Simon Batchelor who carried out all the shooting required for the study at Forfar and District Small Bore Rifle Club.

Shoulder Bone Number	Bullet type	Covering	Distance of spray pattern (mm)
S1	Round	None	28.77
	Flat		42.77
S2	Round	Cotton	17.31
	Flat		16.73
S3	Round	Cotton	20.48
	Flat		22.14
S4	Round	None	39.59
	Flat		42.95
S5	Round	Skin substitute	8.34
	Flat		12.48
S6	Round	Denim	29.04
	Flat		28.67
S7	Round	None	35.37
	Flat		27.33
S8	Round	Skin substitute	45.28
	Flat		43.03
S9	Round	Denim	46.77
	Flat		52.15
S10	Round	Skin substitute	26.91
	Flat		35.87
S11	Round	Cotton	13.29
	Flat		47.18
S12	Round	Denim	43.06
	Flat		43.04

Leg Bone Number	Bullet type	Covering	Distance of spray pattern (mm)
L1	Round	Skin substitute	22.12
	Flat		22.50
L3	Round	None	29.34
	Flat		33.88
L4	Round	Denim	12.35
	Flat		20.26
L5	Round	Cotton	0
	Flat		20.31
L6	Round	Cotton	16.17
	Flat		29.50
L7	Round	None	18.27

	Flat		17.06
L8	Round	None	21.82
	Flat		18.56
L9	Round	Denim	32.71
	Flat		19.17
L10	Round	Denim	3.23
	Flat		0
L11	Round	Cotton	11.27
	Flat		14.12
L12	Round	Skin substitute	32.15
	Flat		34.21
L13	Round	Skin substitute	54.86
	Flat		8.72