TECHNICAL NOTE

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Macroscopic Characteristics of Screwdriver Trauma

ABSTRACT: The main objective of the study was to determine the type of macroscopic trauma created by a flat-tipped and a cross-tipped screwdriver. The second objective was to determine if the trauma inflicted by the two screwdrivers could be macroscopically differentiated. Three tests were conducted, each by a male volunteer. Each test consisted of 12 samples of fleshed pig ribs; six were stabbed with a flat-tipped screwdriver and the remaining six with a cross-tipped screwdriver (Phillips®). Each sample received 15 stab wounds during the process. The stabbings were conducted at perpendicular and oblique angles, with fabric variables being utilized. Results illustrate two main categories of macroscopic skeletal trauma, fractures, and puncture wounds. By studying the macroscopic appearance in tandem with differing trauma frequencies, these two screwdriver types can be differentiated.

KEYWORDS: forensic science, forensic anthropology, macroscopic trauma identification, screwdriver, flat tipped, cross tipped

Screwdrivers are not typical weapons with reference to homicides. However, their use has been noted in various cases, the highest profile of which being the 1970s Yorkshire Ripper Investigation in the United Kingdom (1). Types of weapons used in homicide cases may vary according to the perpetrators socio-economic and environmental circumstances (2). It is clear, when their wide ranging availability is taken into account, that screwdrivers have the potential to be used in homicides, both in impulse killings within the home, where a screwdriver may easily be the first weapon at hand, but also in premeditated or opportunistic homicides outside of the home environment (3). In premeditated cases, perpetrators may choose lightweight and easy to carry weapons (4) that have the potential to be carried on the street discreetly without exciting suspicion. Within the United Kingdom, the Prevention of Crime Act 1953 prohibits any citizen to carry any offensive weapon in public areas ("any article made or adapted for use to causing injury to the person, or intended by the person having it with him for such use" Archbold 24-115B) (5). In addition, the Knife Act 1997 restricts the carrying of offensive weapons and allows the police to stop and search when necessary (6). The possession of a screwdriver may be easily explained away within the stop and search scenario, and can therefore constitute a realistic and easily concealable alternative to more obvious weapons, such as guns or knives.

During the preparation of this project, 15 homicide case studies involving screwdrivers were consulted (1,7–15). Analysis of these cases indicated that 60% of the victims were male, with robbery and drunken assault being the prime motivations behind the homicides. The torso was the main anatomical area of injury in 46% of the cases, followed closely by 40% of cases involving cranial trauma, and 7% accounting for both neck and genital trauma. Just over half of the cases, 54% were committed with a flat-tipped screwdriver, characterized by a tip tapering into a narrow wedge-shaped end, whereas only 20% used a cross-tipped screwdriver (Phillips®), which has four crossed metal protrusions tapering into a pointed end. However, in two of the cases (13%), the type of screwdriver used was not recorded (11,15), and in two other cases (1,15) the screwdrivers used had been sharpened by the perpetrator prior to being used as a homicide weapon. These case studies suggest, therefore, that the most pertinent tools for study are flat-tipped and cross-tipped screwdrivers, although a wider variety of tip shapes and sizes is available.

Previous studies of screwdriver trauma related to homicide incidents have focused on the soft tissue wounds. Brinkmann and Kleiber (7) published the first detailed report of its kind based on a case, where the length and shape of the wounds indented or penetrated into the soft tissue corresponded to the size and shape of a flat-tipped screwdriver. Soft tissue wounds created by such screwdrivers were described as slit-like stab wounds, with angular or rounded ends, which on occasion showed further tearing of the skin (7,8). The first classification of the soft tissue wounds created by a cross-tipped screwdriver was published by Kimura and Nagata (16), based on the autopsy of a suicide victim whose wounds were described as circular, with four equally spaced cuts created by the shape of the screwdriver tip. A later study conducted by Nadjem and Pollak (10), added other possible screwdriver characteristics such as nonpenetrating impact lesions on the skin, and intracutaneous hemorrhages, in addition to addressing the possible manifestation of bone lesions created by flat-tipped screwdrivers.

Very little in-depth research has been conducted with respect to the skeletal trauma created by screwdrivers, and identifying a screwdriver as the murder weapon currently depends mainly on recognizing soft tissue wounds. Ideally, a forensic pathologist would examine the body of a homicide victim shortly after death to assess the damage to soft tissue; in some circumstances however, the body may require careful analysis of internal damage by anthropological analysis, even when the victim has only recently died (17). Bodies may be found in advanced stages of decomposition or skeletonization due to the time lapsed between death and the discovery of the remains (18). In such circumstances, understanding the types of trauma created by screwdrivers on skeletal material may allow accurate identification of a classification of murder weapon in homicides.

In this study, the primary objective was to establish the type of macroscopic trauma created by a flat-tipped and a cross-tipped screwdriver. This will allow more ready interpretation in the mortuary by the forensic anthropologist. The second objective was to determine if the trauma inflicted by the two screwdrivers could be

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differentiated macroscopically. It was hypothesized that due to the physical differences between the two screwdrivers, a variety of differing skeletal traumas would be created.

Materials and Methods

The fleshed assemblages used for this research were from the domesticated pig, *Sus scrofa*. Comparison of the ribs of pigs and humans demonstrates that they are similar in dimension, weight, and structure (19), and therefore working with pig assemblages offers a viable research alterative to working on cadavers. Rib orientation terminology used here is as cited by White and Folkens (20). Study of the rib area also offered the potential for relevant data as studies from around the world show the torso as one of the most consistently injured areas of the body in stabbing cases (4,11,21,22), also illustrated by the case studies consulted.

Three separate tests were carried out, involving 12 individual samples in each test. Nine young adult pig torsos were used during testing, with each of the separated left and the right sides of the rib cage being arbitrarily divided into two samples. Each sample contained five to eight ribs, depending on the size of the bones, which naturally varied between specimens. However, there was a general uniformity in the number of bones present within each of the 12 samples selected for the three tests, with the mean number of ribs present in each sample being six. Each of the 12 samples from each of the three tests was used only once during testing.

The preparation of each sample entailed the removal of the skin followed by the stripping of excess subcutaneous fat. The skin was then sewn back into place using embalming twine to keep it in place during experimentation. A uniform depth of 15 mm was kept for all soft tissue on the external rib surface. This preparation process was necessary for two reasons, one being that pigs generally have a thicker layer of subcutaneous fat than humans, and secondly it was considered important for the samples to retain the skin during experimentation. As more force is required to penetrate skin than muscle (23), experimentation without the skin would have produced unrealistic levels of trauma not applicable to a forensic scenario.

Male volunteers were selected to conduct the experiment, as the literature consulted involved stabbings with screwdrivers that were performed solely by men. Three active and fit male volunteers performed the stabbings, one individual for each test. Each volunteer was from a different age group; the volunteer for Test 1 was in his late 20s, volunteer for Test 2 in his early 60s, and volunteer for Test 3 in his late 30s. Before each test commenced, each individual was instructed to conduct the stabbings with only one hand, and the number of blows was regulated to 15 per sample, as preliminary sampling suggested that this provided trauma on *c.* 50% of the skeletal elements in each sample. The soft tissue wounds were photographed and documented on record sheets, prior to each sample being separately defleshed. To ensure that there was no further alteration to the bone, each sample was simmered in warm water with Biotex, a biological agent, and a degreaser for *c.* 20–30 min. This process made the removal of any remaining soft tissue, either by hand or with the use of a scalpel easier. After complete defleshing, the bones were subsequently photographed, with the documented trauma being recorded on paper.

Variables

The first variable was the use of the two different screwdriver types; of the 12 samples in each test, six were conducted with a flat-tipped screwdriver, and six with a cross-tipped screwdriver. Both screwdrivers used had been in general household use for *c.*5 years. The flat-tipped screwdriver measured 95 mm from handle to tip, and the widest part of the tip 8 mm. The cross-tipped screwdriver measured 75 and 5 mm, respectively. The second variable was the angle at which the stabbing was inflicted. Six of the samples from each test were conducted at a roughly oblique angle, and six at a roughly perpendicular angle. As the motion of manual stabbing does not lend itself to exact precision (24), the angle of the blow was not precise. In addition, the force of the blows was not controlled, as the force applied will vary in forensic cases, just as within this experiment (25).

The third variable was the addition of a fabric covering to eight of the 12 samples in each test; samples 5 to 8 were covered with cotton and samples 9 to 12 with denim. These specific fabrics were chosen as they represent common forms of unisex fabric that have a wide distribution globally. All fabric was new and 100% cotton, and each portion of fabric was used only once during testing. Each covered sample was wrapped in a single layer of the appropriate fabric that was then sewn together on the internal side of each sample to simulate a realistic tension of fabric as the trauma was inflicted. Samples 1 to 4 in each test were left bare. The aim of this variable was to examine whether the presence or absence of the different fabric types made a significant distinction to the skeletal trauma created.

Results

Analysis of the skeletal material from all the three tests demonstrated that the trauma fell into two main categories, fractures and puncture wounds. The full results of the individual experiments are illustrated in Tables 1, 2, and 3 and the combined results in Table 4. Within these main categories, evidence of wastage and bony protrusions was recorded. Wastage referred to fragments of bone detached from the main body of the rib, and discovered lodged within the soft tissues in direct association with the skeletal trauma (Fig. 1). In contrast, protrusions maintain their connection to the main body of the rib and were found either within the trauma itself, or underneath it (Fig. 2). The presence of protrusions indicates that the periosteum and other soft tissues were present at the time of attack (26), as was the case during experimentation.

Fractures

Fractures were present across all the different variables, and are therefore a primary characteristic of screwdriver trauma. The fractures have been categorized first as complete or incomplete, second as transverse, longitudinal or oblique, and third, as direct or indirect (27,28).

The flat-tipped screwdriver produced 16 fractures in total, with 44% (seven examples) being complete and 56% (nine examples) being incomplete. Overall, the fractures from the flat-tip samples were predominantly transverse, accounting for 88% (14 examples) of fractures in all the three tests (Fig. 3). Within the flat-tipped results, Tests 1 and 2 had only transverse fractures present, occurring as both complete or incomplete, and direct or indirect. Test 3, sample 2 (flat tipped/perpendicular/bare) exhibited the only examples of longitudinal or oblique fracturing within the flat-tipped samples, each representing 6% (one example) of the total flat-tipped fractures. This longitudinal fracture is the only example of this fracture type with wastage from all the three tests. Overall, in the flat-tipped results, direct fractures were much more frequent than indirect fractures with 69% (11 examples) being direct, compared with 31% (5 examples) indirect. All five examples of indirect fractures

TABLE 1—*Categories of skeletal trauma and occurrence patterns in Test 1.*

				Fractures									Puncture Wounds			
				Complete				Incomplete					Edge		Body	
				Transverse		Longitudinal		Transverse		Longitudinal		Oblique				
SD	Angle	Fabric	Sample no.	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Partial	Total	Partial	Total
Flat	Oblique	Bare	1		2				1				2(1w)	1		
		Cotton	5	1				1						2(2w)	1	1
		Denim	9	1					1						1	
	Perpendicular	Bare	2					1	1					2(2p)		1
		Cotton	6					1						2(2p)		3(3p)
		Denim	10													
Cross	Oblique	Bare	3	1										2(1p)	1	1(p)
		Cotton	7					1						5(1p, 1w)		
		Denim	11											2(2w)		
	Perpendicular	Bare	4	1				1						2(2p)		2
		Cotton	8	1										1(p)		1
		Denim	12							2		3		1(p)		3(p)

SD, Screwdriver; p, protrusions; w, wastage.

TABLE 2—*Categories of skeletal trauma and occurrence patterns in Test 2.*

				Fractures									Puncture Wounds			
				Complete				Incomplete					Edge		Body	
				Transverse		Longitudinal		Transverse		Longitudinal		Oblique				
SD	Angle	Fabric	Sample no.	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Partial	Total	Partial	Total
Flat	Oblique	Bare	1	1				1						1(p)	1	
		Cotton	5													
		Denim	9													
	Perpendicular	Bare	2													
		Cotton	6													
		Denim	10													
Cross	Oblique	Bare	3	1						1					1	2
		Cotton	7													
		Denim	11											1(w)		
	Perpendicular	Bare	4					1						1(p)		
		Cotton	8					1							1	1(p)
		Denim	12	2		1		1		2				1(p)	1	3(3 p&w)

SD, screwdriver; p, protrusions; w, wastage.

TABLE 3—*Categories of skeletal trauma and occurrence patterns in Test 3.*

				Fractures									Puncture Wounds			
				Complete				Incomplete					Edge		Body	
				Transverse		Longitudinal		Transverse		Longitudinal		Oblique				
SD	Angle	Fabric	Sample no.	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Partial	Total	Partial	Total
Flat	Oblique	Bare	1													
		Cotton	5													
		Denim	9													
	Perpendicular	Bare	2	1		1(w)		1				1		2(2p)		1
		Cotton	6													
		Denim	10													
Cross	Oblique															
		Bare	3					1		1				1(w)		1(w)
		Cotton	7												1	
		Denim	11													
	Perpendicular	Bare	4					1							1	1
		Cotton	8							1						1(p)
		Denim	12												2	1(p)

SD, screwdriver; p, protrusions; w, wastage.

TABLE 4—*Combined categories of skeletal trauma and occurrence patterns in Tests 1, 2, and 3.*

				Fractures									Puncture Wounds			
				Complete				Incomplete					Edge		Body	
				Transverse		Longitudinal		Transverse		Longitudinal		Oblique				
SD	Angle	Fabric	Sample no.	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Partial	Total	Partial	Total
Flat	Oblique	Bare	1	1	2			1	1				2(1w)	2(1p)	1	
		Cotton	5	1				1						2(2w)	1	1
		Denim	9	1					1						1	
	Perpendicular	Bare	2	1		1 (w)		2	1			1		4(4p)		2
		Cotton	6					1						2(2p)		3(3p)
		Denim	10													
Cross	Oblique	Bare	3	2				1		2				3(1p, 1w)	2	4(1p, 1w)
		Cotton	7					1						5(1p, 1w)	1	
		Denim	11											3(3w)		
	Perpendicular	Bare	4	1				3						3(3p)	1	3
		Cotton	8	1				1		1				1(p)	1	3(2p)
		Denim	12	2		1		1		4		3		2(2p)	3	7(3p&w, 2p)

SD, screwdriver; p, protrusions; w, wastage.

FIG. 1—*Puncture wound on edge of rib, with wastage. Note attached denim fiber on bone fragment. External surface. Test 1, sample 11 (cross tipped/oblique/denim).*

FIG. 2—*Puncture wound on edge of rib, with bony protrusions. External surface. Test 1, sample 4 (cross tipped/perpendicular/bare).*

are found in Test 1, these all being transverse, and both complete and incomplete. Four of these are in samples 1 (flat tipped/oblique/bare) (Fig. 3) and 2 (flat tipped/perpendicular/bare) with no

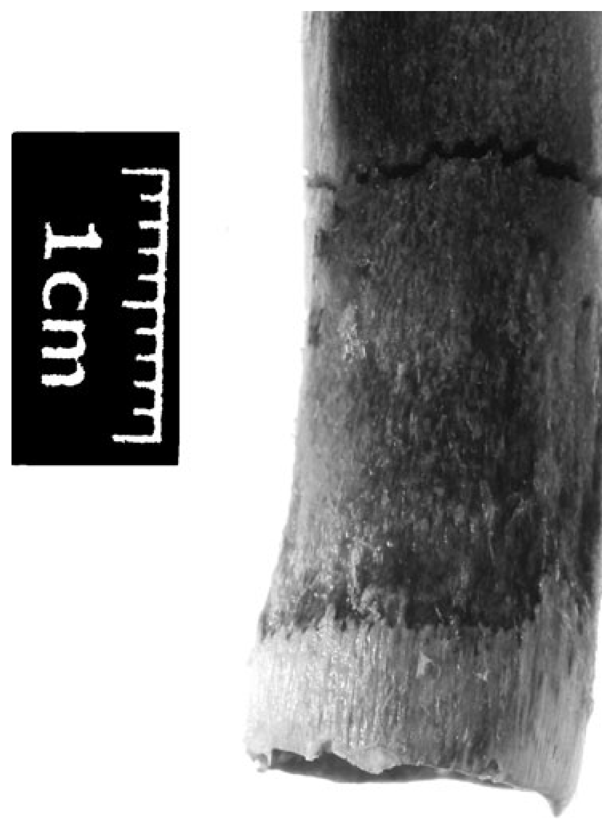

FIG. 3—*Incomplete indirect transverse fracture with bone separation on the internal surface. Test 1, sample 1 (flat tipped/oblique/bare).*

fabric covering, while one example occurred in sample 9 (flat tipped/oblique/denim).

The flat-tipped results also show that the differing angles of stabbing produce roughly similar numbers of fractures, with the oblique being slightly more successful resulting in 56% (nine examples) of overall flat-tipped fractures, when compared with 44% (seven examples) produced by the perpendicular angle. There is a clear pattern evident in the numbers of fractures in comparison with the fabric variables, with 69% (11 examples) of all the fractures created by the flat-tipped screwdriver occurring in the samples without fabric. The number of fractures present then decreases as the thickness of the fabric increases, to 19% (three examples) of fractures occurring with the flat-tipped screwdriver and the cotton, and 12% (two examples) with the flat tipped and the denim. This is further emphasized by the total absence of fractures within the cotton and denim samples in both Tests 2 and 3; only Test 1 showed the flat-tipped screwdriver creating fractures through the fabric.

More fractures are created with the cross-tipped screwdriver than with the flat tipped (24 fractures compared with 16). As with the flat-tip results, the cross-tipped screwdriver created more incomplete fractures than complete ones, 71% (17 examples) compared with 29% (seven examples). The dominant form of fracture for the cross-tipped screwdriver is transverse, accounting for 54% (13 fractures) of the fractures across all the three tests. The remaining fractures were longitudinal, 34% (eight examples) and oblique, 12% (three examples). The longitudinal fractures were present in all the three cross-tipped tests; all were direct and incomplete (Fig. 4) with the exception of one example from Test 2, sample 12 (cross tipped/perpendicular/denim). The oblique fractures occurred only within Test 1, sample 12 (cross tipped/perpendicular/denim). All of the fractures created by the cross-tipped screwdriver were direct, 100% (24 examples).

Within the cross-tipped screwdriver results, the perpendicular angle created more fractures than the oblique, with 75% (18 examples), compared with the remaining 25% (six examples) from the oblique angle. A difference is apparent in the rates of fracture trauma created when compared with the fabric variables, as the samples covered in the denim had the highest numbers of fractures in the cross-tipped samples, 46% (11 examples). The samples without the fabric were the second highest, 38% (nine examples) and the cotton had the lowest fracture rates, 16% (four examples).

Puncture Wounds

Puncture wounds (29), the other main form of trauma present in the results, were created by the direct impact of the screwdriver to the bone. All trauma in this category was direct, and in most cases the resulting trauma could be macroscopically identified with respect to the size and shape of the screwdriver used (Figs. 5 and 6). Screwdriver impressions are particularly clear when the puncture wound occurs on the main body of the rib (for comparison purposes see Figs. 1, 2, 5, and 6). For this reason, puncture wounds were categorized according to the extent of bone penetration and location. Bone penetration is either partial, having broken only the external

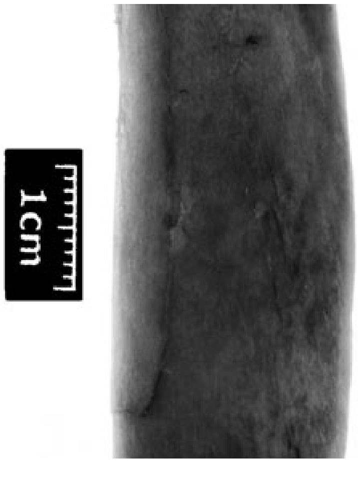

FIG. 4—*Incomplete direct longitudinal fracture on internal rib surface. Test 1, sample 12 (cross tipped/perpendicular/denim).*

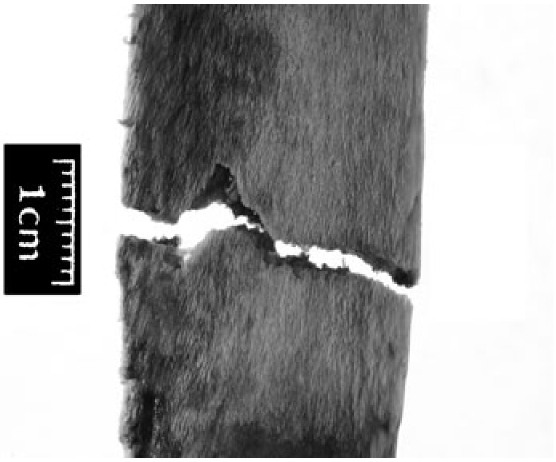

FIG. 5—*Puncture wound from flat-tipped screwdriver. A total penetration of the main body of the rib, with complete direct transverse fracture. External surface. Test 1, sample 5 (flat tipped/oblique/cotton).*

FIG. 6—*Puncture wound from cross-tipped screwdriver, total penetration of the main body of the rib. External surface. Test 1, sample 3 (cross tipped/oblique/bare).*

surface of the rib, or total, with the screwdriver having broken through the internal side of the rib into the chest cavity. The locations of the puncture wounds were on the cranial or caudal rib edges, or on the main body of the rib. This variation in location of the puncture wounds depends only on the chance striking of the screwdriver, but results in a slight difference in trauma morphology. Puncture wounds that occurred on the cranial or caudal edges of the ribs were more prone to wastage (Fig.1), and bone protrusions (Fig. 2), than those on the main body of the rib, although these were still seen in some examples. As a result, impressions of the tool used could be distorted, and it has been found that puncture wounds on the main body of the rib where the bone is more stable created clearer impressions. In this instance, the inside surface of the wound could be enhanced by the use of an impression kit if necessary. This was tested on several examples during this project using a two-part dental impression kit containing polyvinylsiloxane that proved effective at replicating the internal surface of the skeletal trauma.

The flat-tipped screwdriver created 21 puncture wounds. The greatest number was in Test 1 containing 77% (16 examples) of the overall amount of puncture wounds created by the flat-tipped screwdriver, with Test 2 containing 9% (two examples), and Test 3 14% (three examples). Total penetrations were more common than partial penetrations: 76% (16 examples) compared with 24% (five examples) of total flat-tipped punctures. All the puncture wounds on the main body of the rib were rectangular in formation, differing only in depth, and the presence or absence of associated fractures or protrusions. Over half, 62% (13 examples) of all the puncture wounds created by the flat-tipped screwdriver exhibited either wastage or protrusions; these were mostly from trauma on the cranial or caudal edge, except three examples from Test 1, sample 6 (flat tipped/perpendicular/cotton). All the examples with wastage or protrusions were total penetrations, with one exception in Test 1, sample 1 (flat tipped/oblique/bare).

The puncture wounds created by the flat-tipped screwdriver occurred at both the oblique angle, 48% (10 examples), and perpendicular angle, 52% (11 examples). All the perpendicular punctures were total penetrations of the bone, and in the 10 oblique examples, five were total and five partial. There was a pattern in the frequency of this trauma type in relation to the fabric variables; Test 1 was the only test to have puncture wounds from the flat-tipped screwdriver in the samples covered with cotton or denim. Tests 2 and 3 had none, and overall there was a decrease in this kind of trauma as the fabric variables were added: 53% (11 examples) occurred in the samples with no fabric, 43% (nine examples) with the cotton, and 4% (one example) with the denim (Test 1, sample 9: flat tipped/oblique/denim).

The cross-tipped screwdriver results totaled 42 puncture wounds. The greatest number were in Test 1 which contained 50% (21 examples) of the overall amount of puncture wounds created by the cross-tipped screwdriver, Test 2 contained 29% (12 examples) and Test 3, 21% (nine examples). Most of the penetrations on the main body of the rib were cruciform in shape. Total penetrations were far more frequent than partial penetrations, 81% (34 examples) compared with 19% (eight examples). Just over half, 60% (25 examples), of all the puncture wounds created by the cross-tipped screwdriver exhibited either wastage or protrusions; of these, there were 13 examples of trauma from the cranial or caudal edge, and 12 from the main body of the rib. All the examples with wastage or protrusions were total penetrations of the bone.

The puncture wounds created by the cross-tipped screwdriver occurred at both the perpendicular and oblique angles, 57% (24 examples) perpendicular and 43% (18 examples) oblique. In the perpendicular samples, 19 were total penetrations of the bone, and in the oblique samples, 15 punctures were total and three partial. There was no consistent pattern in the frequency of puncture wounds in relation to the fabric variables with the cross-tipped screwdriver results, as trauma was present both with and without the fabric; 38% (16 examples) on the bare samples, 26% (11 examples) with the cotton and 36% (15 examples) with the denim.

Discussion

Test 1 provided one of the most interesting sets of results, having the largest amount and variety of trauma. Trauma is present in 11 out of the 12 samples, compared with six out of 12 samples in both Tests 2 and 3. There are 57 individual trauma sites in Test 1, over twice the number of the other two tests. This increase may be due in part to a factor not controlled during experimentation, the placement of the screwdriver strike on the sample; as blow positions were not specified, there was a certain amount of chance involved as to where trauma was created. However, it also seems plausible that there is a link between the highest trauma frequency and the fact that Test 1 was stabbed by the youngest male volunteer (late 20s). This suggests that the capability to create skeletal screwdriver trauma is increased if the perpetrator is a younger adult male, possibly due to a higher level of force behind the impact of the screwdriver that may potentially decrease with age. The fact that Tests 2 and 3 with their similar numbers of trauma sites (26 and 20 respectively), did not decrease directly in tandem with volunteer age suggests that this is not a constant; but given that the trauma amount declined considerably, it suggests that there was overall more force used by the youngest volunteer.

There were patterns also in the absence of trauma across the individual samples. In the flat-tipped screwdriver samples, in all three tests, sample 10 (flat tipped/perpendicular/denim) had no skeletal trauma. Test 1, confirming again that more force was used in the attack, had two total penetrations only of the denim and soft tissue, while in Tests 2 and 3 the screwdriver failed to penetrate the denim resulting overall in no skeletal trauma in this sample. This consistently low-sample penetration rate established the inability of the flat-tipped screwdriver at the perpendicular angle with the denim to create skeletal trauma. Indeed, the flat-tipped screwdriver samples overall provided less trauma than the cross tipped, as in Tests 2 and 3 there was no trauma in samples 5, 6, and 9, as well as 10. It is clear that the flat-tipped screwdriver had difficultly in penetrating the fabric variables. The presence of trauma in Test 1 showed that it is not impossible, but, as discussed above, suggests that a greater level of force is required than was present in Tests 2 and 3.

In comparison, the cross-tipped samples had no consistent pattern in the absence of trauma; there was no sample which failed to exhibit trauma more than once during the three tests. Trauma was absent in Test 2, sample 7 (cross tipped/oblique/cotton) and Test 3, sample 11 (cross tipped/oblique/denim), indicating that the cross tipped was less successful at creating trauma at the oblique angle than the perpendicular, and that fabric was an impediment. The fact that this occurred once out of three tests implies that it was not a constant, and it was probably related to the force used, as an absence of cross-tipped trauma occurred only in Tests 2 and 3. It is notable that in comparison to the difficultly of the flat tipped to create trauma in sample 10, the cross-tipped equivalent sample (12: cross tipped/perpendicular/denim) had trauma in each of the three tests.

The samples across the three tests which consistently contained trauma are all from the cross-tipped screwdriver: samples 3 (cross tipped/oblique/bare), 4 (cross tipped/perpendicular/bare), 8 (cross tipped/perpendicular/cotton), and 12 (cross tipped/perpendicular/denim). It is clear that the results of this project indicate that the cross-tipped screwdriver more consistently created trauma across all the variables than the flat tipped.

For both types of screwdriver, the most frequent fracture type was transverse, both complete and incomplete; transverse fractures can be seen to be characteristic of screwdriver trauma. However, they are not useful to differentiate between screwdriver types, as they occur across all the variables. Longitudinal fractures are potentially more effective for this, as they are seen almost exclusively in cross-tipped samples across all the three tests. However, there was one example from the flat-tipped screwdriver (Test 3, sample 2: flat tipped/perpendicular/bare), occurring at the costal end of the rib, and running straight into the cut area where the cartilage was removed during the butchery process. It is possible that in this isolated example the longitudinal and oblique fracturing was a response to the traumatic force in a weakened area of bone. This example had a slightly different form to the more consistent longitudinal fracturing visible in the cross-tipped samples, as it is the only example with associated wastage; a large fragment became detached at the costal end, emphasizing the weakened state of this area of bone.

It is likely that oblique fracturing was a variation on the longitudinal fracturing, as it only appeared in samples with longitudinal fractures, and was on occasion in direct association with these (Test 3, sample 2: flat tipped/perpendicular/bare). However, longitudinal fracturing occurred alone, without oblique fractures, and has a higher rate of occurrence. It is probable that they both are a response to the more varied structure of the cross-tipped screwdriver, giving a greater variety of trauma on the bone than the flat-tipped screwdriver.

Indirect fractures were present only in Test 1, and were once again suggestive of the use of a higher level of force than was present in Tests 2 and 3. This type of fracturing occurred beyond the site of immediate trauma (26) as the screwdriver impacted either within the intercostal space or on a neighboring rib. The excess energy created by the blow dissipated through the soft tissue with enough force to create indirect fractures. These occurred only in the flat-tipped screwdriver samples, at both oblique and perpendicular angles, and with the exception of one denim sample, all were in bare samples.

Additional factors that may influence the formation of indirect fractures were screwdriver structure and the fabric variables. The broader tip of the flat-tipped screwdriver, when compared with the cross tipped, covered a larger surface area and is more likely to penetrate near bone. It was also less likely than the latter to penetrate into the chest cavity, avoiding dispersing the excess energy into an area away from the ribs. The results also indicated that the fabric had an effect; indirect fractures were more likely to occur when fabric was not present, suggesting that the fabric may have absorbed some of the excess energy and slowed its spread throughout the sample.

In relation to the fabric variables, the flat-tipped screwdriver exhibited a clear pattern; the number of fractures present declined as the fabric thickness increased. In contrast, the cross-tipped screwdriver in conjunction with the denim samples, had the highest fracture rate, followed by the bare and then the cotton. At the oblique and perpendicular angles, the flat-tipped screwdriver produced similar fracture rates, but the cross tipped showed a clear tendency to create more fractures at the perpendicular angle.

The cross-tipped screwdriver had a greater ability to inflict puncture wounds than the flat tipped, which created exactly half the number of the former. Test 1, once again, produced the highest rate of trauma for both the flat- and cross-tipped results. Both the cross-tipped and the flat-tipped screwdrivers had similar frequencies of penetrations, with the number of total penetrations in both cases being far higher than partial, stressing that screwdrivers easily penetrated bone through soft tissue.

The ability of the flat-tipped screwdriver in puncturing the bone had a direct correlation with the fabric type, either showing a sharp decrease in frequency (Test 1) or a total inability to do so when cotton or denim was present (Tests 2 and 3) suggesting that the fabric offered some degree of protection to the skeletal elements. In contrast, the cross-tipped screwdriver penetrated both the cotton and denim, producing similar trauma rates with denim to that seen in bare samples.

Complete puncture wounds on the body of the rib had the advantage of providing direct information about the weapon used. The cross-tipped samples exhibited cruciform impressions that were clearly visible macroscopically, and many exhibited further associated trauma. The cruciform impression was apparent on both the external and internal surfaces of some examples, although in others, the external cruciform shape had been erased by the passage of the screwdriver shaft into the bone (Fig. 7). However, the shape was still visible on the internal rib surface, and within the wound structure, permitting an easier diagnosis to be made. Complete puncture wounds created by the flat-tipped screwdriver were usually rectangular in formation, and occurred frequently on both the internal and external rib surfaces. Of interest, here is sample 6 from Test 1, with three total puncture wounds in close relationship, giving the impression of a frenzied attack, where the stabs were inflicted in close succession (Fig. 8). In only two examples, complete punctures were not directly diagnostic of the screwdriver used (Test 2, sample 12: cross tipped/perpendicular/denim; and Test 3, sample 2: flat tipped/perpendicular/bare). It is probable that this is due to the use of a twisting or gouging motion, causing a greater degree of fragmentation to the external surface of the bone.

Over half of the puncture wounds exhibited either wastage or protrusions, or a combination of the two. Both wastage and protrusions were mostly associated with puncture wounds on the edge of the rib, and barring one example, all were total penetrations. With both screwdrivers, wastage was most likely to occur at the oblique angle (Table 5), suggesting that the screwdriver scraped across the bone and dislodged fragments, particularly at the bone edge. Indeed, wastage never occurred with the flat tipped at the perpendicular angle, and with the cross tipped it occurred less frequently than at the oblique.

In relation to the fabric variables (Table 6), the flat-tipped screwdriver created wastage within the bare and the cotton samples.

FIG. 7—*Puncture wound where the cruciform impression has been erased on the external surface, but remains on the internal side and within the wound. External surface. Test 1, sample 4 (cross tipped/perpendicular/bare).*

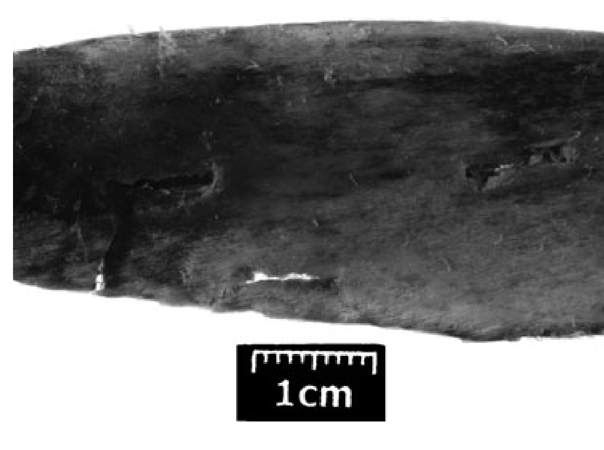

FIG. 8—*Three puncture wounds, all total penetrations, in close association. External surface. Test 1, sample 6 (flat tipped/perpendicular/cotton).*

TABLE 5—*Frequency rates of wastage and protrusions with the angle variables.*

	Oblique	Perpendicular
Cross tipped		
Wastage	6	3
Protrusions	3	13
Flat tipped		
Wastage	3	—
Protrusions	1	9

In contrast, the cross tipped created wastage across all the fabric variables, having a high frequency rate with the denim. Once again, these factors demonstrate that the tip of the cross-tipped screwdriver creates a wider variety of trauma in larger amounts than the flat tipped. However, it is possible that wastage may be an artificial category seen only within laboratory experiments, as decomposition of the soft tissue in unregulated circumstances is likely to remove the association of the fragments to the skeletal trauma. The authors are currently researching this.

Puncture wounds occurred also with protrusions. These happened at both angles, but there was a strong propensity for protrusions to occur in the largest number at the perpendicular angle with both types of screwdriver (Table 5). As with wastage, protrusions were not observed with the flat-tipped screwdriver and the denim, due to the lack of screwdriver penetration, but were seen with the cross tipped and the fabric variables. Within the flat-tipped samples, wastage and protrusions never occurred on the same specimen, demonstrating that the structure ensures a simpler relationship to trauma types than the cross tipped.

There were examples of puncture wounds without wastage or protrusions, and this may be due to several factors. As mentioned above, wastage may lose its association with trauma during the defleshing process. Alternatively, it may be due to the variables involved, but it was difficult to ascertain a pattern to this. The cross-tipped screwdriver results contained more examples of puncture wounds without wastage or protrusions than the flat tipped, but this may be arbitrary, and is also the subject of future research.

There were other findings from the results that did not occur with enough frequency to be regarded as a characteristic of screwdriver trauma. This included two examples of grazing, both from Test 1, sample 7 (cross tipped/oblique/cotton) and sample 11 (cross tipped/oblique/denim). It is likely that grazes were created by the metal protrusions on the screwdriver tip scraping the bone surface as the screwdriver passed in close proximity at an angle, lightly abrading the surface of the adjacent bone (Fig. 9). The resulting trauma cannot really be termed a puncture wound as the bone was not penetrated beyond some minor surface splintering, and there was no associated trauma. As grazes only occurred in the cotton and denim samples, this suggested that they were created when sufficient force was applied to drive the screwdriver through the fabric, and yet when there was insufficient force present to cause further trauma such as fracturing. As these were isolated examples, this form of trauma requires further research, but these preliminary results suggest that grazes can be indicative of the type of screwdriver and the angle of attack, and also suggestive of the presence of soft tissue wounds prior to skeletonization.

TABLE 6—*Frequency rates of wastage and protrusions with the fabric variables.*

	Bare	Cotton	Denim
Cross tipped			
Wastage	2	1	6
Protrusions	5	4	7
Flat tipped			
Wastage	1	2	—
Protrusions	5	5	—

FIG. 9—*A graze on the edge of a rib. Test 1, sample 7 (cross tipped/oblique/cotton).*

Test 1, sample 11 (cross tipped/oblique/denim) also presented an example where a small portion of the electro plating from the screwdriver surface was embedded in the bone (Fig. 10). This was visible macroscopically, but has been magnified slightly for publication. As the screwdriver used in experimentation had been in previous use, it seems possible that this material could have shed from the screwdriver at any point during testing. This may have also occurred in other samples without the evidence surviving the defleshing process, highlighting the need for careful examination prior to defleshing. However, the fact that this sample was wrapped in denim, and that the screwdriver material was embedded into the bone surface suggests that this blow was conducted with a large amount of force, although no associated trauma was visible. A similar finding still present after defleshing was a denim fiber attached to the bone wastage from Test 1, sample 11 (cross tipped/oblique/denim) (Fig. 1). These findings have very little to do with the variables involved, but have been included for reference purposes, as

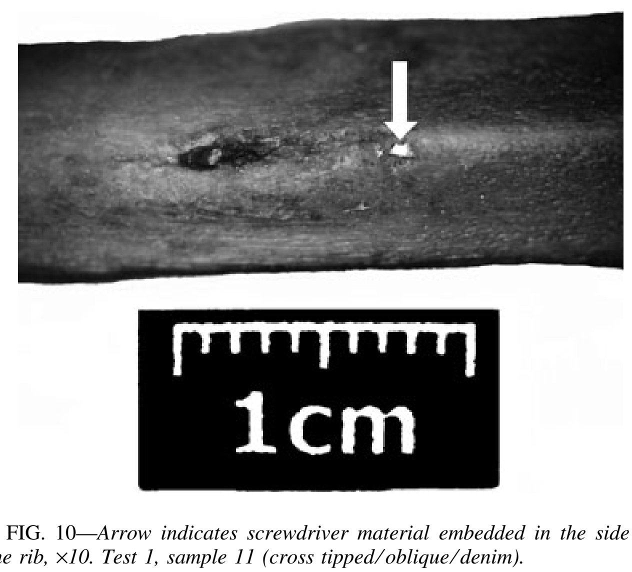

FIG. 10—*Arrow indicates screwdriver material embedded in the side of the rib, ×10. Test 1, sample 11 (cross tipped/oblique/denim).*

such observations are of forensic importance within a medicolegal investigation.

Summary

The results have illustrated two main categories of macroscopic skeletal trauma created by these particular flat and cross-tipped screwdrivers. Both fractures and puncture wounds occurred in different forms, and provided information that can be used to better identify and differentiate the screwdriver type used. This can be accomplished in two complementary ways; first, by the visual identification of puncture wounds that are directly diagnostic of the screwdriver used during the attack. Second, it is possible to differentiate between flat and cross-tipped trauma by studying the frequency patterns of the exhibited trauma. However, it is clear that these findings constitute a preliminary investigation, and the various forms of trauma exhibited within the results of this project need more analysis than was possible with the available sample size. It is for this reason that the authors are currently undertaking further research on this topic.

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