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Macroscopic Characteristics of Hacking Trauma*

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ABSTRACT: Hacking trauma is often encountered in forensic cases, but little experimental research has been conducted that would allow for the recognition of wounds caused by specific weapon types. In this paper, we report the results of a hacking trauma caused by machete, cleaver, and axe weapons and the characteristics of each weapon type on bone. Each weapon type was employed in multiple trials on pig (*Sus scrofa*) bones and then the wounds were examined macroscopically for several characteristics that serve to differentiate the weapons.

KEYWORDS: forensic science, forensic anthropology, sharp-force trauma, hacking trauma, cut marks, weapons, cleavers, axes, machetes, tools

Trauma produced by metal weapons is commonly encountered in forensic cases. Fourteen percent of all murders and nonnegligent manslaughters committed in the United States and known to police in 1996 were accomplished using knives or other cutting instruments (1). Although slashing or hacking wounds from metal weapons are reported occasionally in the forensic literature (2–4), most published forensic reports have concentrated on the appearance and character of stab wounds or the ability to distinguish the implements used in saw-mark cases (5–11). However, the use of hacking metal weapons is common, and although the general appearance of hacking wounds has been reported, little experimental research has been conducted with hacking weapons to examine specific tool characteristics, reproducibility, or other factors of hacking trauma. This study was undertaken to determine if a reasonable set of generalizations about the effects of differing hacking weapons on long bones could be made and used in the determination of weapon type.

Previous Research

Much of the literature on hacking trauma is focused on skeletal remains from 14th to 17th century Old World archaeological contexts (12–18). Based on replicative experiments utilizing swords and axes, Wenham identified a series of characteristics that are diagnostic of a bone cut by a severe hacking blow and independent of type of blade used (12). A summary of his findings includes the following three criteria:

1. At least one side of the injury shows a smooth, flat surface cut by the blade. If the blade enters the bone at an angle other than 90°, the obtuse-angled side shows a smooth cut surface. The acute-angled side terminates in fractured bone (Fig. 1).
2. On the acute-angled side, the outer surface of the bone is detached from the underlying bone as thin flakes. In ancient material, the flakes are normally lost, but in the experimental bone injuries, the flakes remained held in place by the membrane that surrounds the bone.
3. Injuries also frequently show large areas of bone broken away from beneath the blades as they passed through skeletal elements.

Examination of documented cases of hacking trauma at the Armed Forces Institute of Pathology (AFIP) verified all of Wenham's observations (19). However, all cases observed at the AFIP were crania. Postcranial elements have a different topography than cranial elements. Furthermore, questions of variation between different weapons of a particular type and replicability of wound characteristics remained. Thus, the experiments detailed below were conducted to derive observations from cases with known parameters.

Methods and Sample

We examined the characteristics of hacking trauma by using three types of weapons—machete, axe, and cleaver—to produce trauma to the severed limbs of domesticated pigs. The weapon types were chosen for the differences in the sizes of their heads, wedge thickness, weight, and length of handle. In a pilot study, we used the fully fleshed limbs of three domesticated pigs. Earlier work by Bonte (20) demonstrated that trauma produced by hacking weapons could not result in full amputation of the limb unless the limb was braced in the opposite direction of the blow. As we wished to prevent amputation if possible, one of the two male observers manually held each limb while the second inflicted trauma to it with each of the weapons in turn, with each observer using each weapon once. No particular attention was paid to direction of the blow. The limbs were placed in labelled one-gallon jars along with enough distilled water to fill them for maceration. The limbs were macerated over a three-month period in an aluminum outbuilding; each jar was opened twice to replace the water. Once the flesh was sufficiently disintegrated, the bones were removed, washed in distilled water, and laid out to dry for a week. The process of maceration had caused the unossified epiphyseal ends to disintegrate and we concluded that any blows inflicted close to the proximal or distal ends of the bones would provide no useful data.

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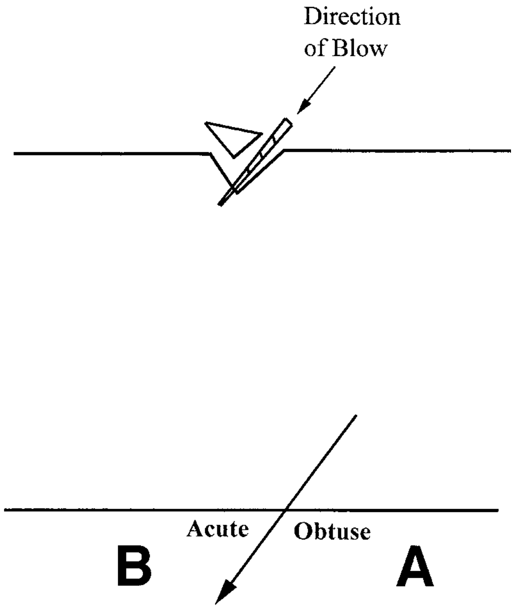

FIG. 1—*Characteristic wound patterns of wedge-shaped weapons applied by slashing or hacking (Wenham 1989: figure 8.10 a & b).*

TABLE 1—*Width of weapons at sharp and blunt edges serving as a measure of wedge (measures are mean measures of the three observers).*

Specimen	Width at Sharp Edge (mm)	Width at Blunt Edge (mm)
Cleaver 1	0.65	1.94
Cleaver 2	na	na
Cleaver 3	0.62	1.82
Mean Cleaver	**0.63**	**1.88**
Machete 1	1.40	2.15
Machete 2	na	na
Machete 3	1.25	2.78
Mean Machete	**1.32**	**2.46**
Axe 1	1.25	33.46
Axe 2	1.67	29.22
Axe 3	1.29	27.83
Mean Axe	**1.40**	**30.17**

Many of the wounds were not deep enough to provide useful data, and these specimens were discarded, our methodology modified, and a second set of trials begun.

Our second set of specimens consisted of 28 moderately fleshed and severed domesticated lower pig limbs. These elements were placed on a wooden block and trauma was inflicted manually; while this contradicted our earlier stated desire to avoid amputa-

TABLE 2—*Independent observations of six characteristics by three observers. The numbers represent the number of observers who reported a particular characteristic. Missing observations do not indicate disagreement among observers. In some cases one of the observers did not report on a particular wound and the total will sum to less than three, but all disagreements are presented. Symbols for cut type are: P = perpendicular, O = oblique.*

Specimen #	Cut	Immediate Fracture		Discern Entry		Discern Exit		Appearance of Entry Wound					Appearance of Exit Wound					Smooth Exit?	
Axe	Type	Yes	No	Yes	No	Yes	No	Clean	Chat	Crush	Fract	Other	Clean	Chat	Crush	Fract	Other	**Yes**	No
1A - Femur	P	2	1	3		2	1			3						3			3
1B - Humerus	P	3		3		2		1		2				1		2			3
1C - Tibia	P		3	3		2		2	1					1		2			2
1D - Ulna	P		3	3		3		1	2					1		2			2
2A - Femur	P		3	3		3		1	1	2						3			3
2B - Femur	P	1	2	3		3			3							3			2
2C - Femur	P		2	3		3		2			1					3			2
3A - Femur	P	2	1	2	1	1	2		1	1						2			
3B - Femur	P		3	3		3			2	1						2			2
3C - Femur	P		3	3		3			2	1						3			2
Machete																			
1A - Femur	O		3	3		3		3								3			3
1B - Femur	O		3	3		2		3						1		2			
1C - Femur	O		2	2		2		2								1			
1C - Femur	P		2	2		2			2							2			2
2A - Femur	P		3	3		3		3									Floor		1
2A - Femur	O		1	1			1	1								1		1	
2B - Femur	P		3	3		3		3	1							3			3
2C - Tibia	P		3	3		3		3								3			3
3A - Tibia	P		3	3		3		3	1	1						3			3
3B - Femur	P		3	3		3		3	2							3			2
3C - Femur	P	1	1	1	1	1	1												
Cleaver																			
1A - Femur	O		3	3		2		3						2		3			2
1A - Femur	P	1	1	2		2					2						Floor		
1B - Tibia	P		3	3		3		3									Floor		
1C - Femur	P		3	3		3		3									Floor		
1C - Femur	O		2	2		2		2									Shave		
2A - Tibia	O		3	3		3		3								3			3
2B - Humerus	P		3	3		3		3	1	1							Floor		
2B - Humerus	O		2	2		2		2	1	1							Floor		
2C - Tibia	P		2	2		2		2									Floor		
2C - Tibia	O		3	3		3		3								2			2
3A - Femur	P		3	3		3		3									Floor		
3B - Femur	P		3	3		3		3									Floor		2
3C - Femur	P		3	3		3		3									Floor		

tion, it allowed for much more control of the direction of the blow. The force of the blows was not regulated and blows were made by both male and female protagonists. Three examples of each weapon type (machete, axe, and cleaver) were used. All weapons were previously used as tools and exhibited scratches and dents along the blade edge and surface. The only exception was Cleaver 1 which was new and had never been used prior to the experiment. The width of each weapon blade at the sharp edge and at the blunt other side was taken as a measure of the weapon wedge and is presented in Table 1. Each specific weapon ($n = 3$) of each weapon type ($n = 3$) was used to inflict trauma on three different elements, with the exception of Axe 1 which was used on one additional element, for a total of 28 experiments (Table 2). Whenever possible, blows were directed at two angles for each element, resulting in two wounds, one oblique to the long axis of the bone (at approximately 45°) and one perpendicular to the long axis of the bone (at approximately 90°). This yielded a sample of ten limbs with damage from axes and nine limbs each with damage from cleavers and machetes.

The elements were defleshed following trauma by boiling in cheesecloth bags with separate labels in each bag listing weapon type, weapon number, and trial number. They were then analyzed for nine characteristics independently by three observers (Table 3). Among the characteristics were discernible entry and exit, appearance of entry and exit, and percentage of bone cut prior to fracture. Appearance of the entry and exit wounds was characterized as **clean cut, chattering** (a series of small fragments or "chips" caused by the vibrations of the weapon), **crushing** (small to medium pieces of bone pushed in directly by the weapon in the direction of the blow), and **fracture** (medium to large pieces of bone broken not only directly by the weapon in the path of the blow but along fracture lines radiating outward from the actual blow). Following an independent observation and grading of the wound characteristics for each skeletal element by three observers (Humphrey, Hutchinson, and Tucker), observations were compared and reanalyzed, and a consensus among the researchers was derived.

TABLE 3—*Data recording sheet for macroscopic observations of hacking trauma.*

MACROSCOPIC OBSERVATIONS OF HACKING TRAUMA				
OBSERVER =		DATE OF OBSERVATION =		
SPECIMEN # =		ELEMENT =		
WEAPON TYPE =		TYPE OF WOUND (OBLIQUE -- PERPENDICULAR)		
A. GENERAL OBSERVATIONS			YES	NO
1. IMMEDIATE FRACTURE?				
2. DISCERNIBLE ENTRY?				
3. DISCERNIBLE EXIT?				
B. SPECIFIC OBSERVATIONS				
4. APPEARANCE OF THE ENTRANCE WOUND				
CLEAN CUT	CHATTERING	CRUSHING	FRACTURE	OTHER
5. APPEARANCE OF THE EXIT WOUND				
CLEAN CUT	CHATTERING	CRUSHING	FRACTURE	OTHER
FOR BONES EXHIBITING AT LEAST SOME CLEAN CUT SURFACE:			YES	NO
6. DID THE SMOOTH CUT OCCUR ON EXIT?				
7. WHAT PERCENT OF THE BONE WAS CUT BEFORE FRACTURE?				
8. AT WHAT POINT DID THE FRACTURE OCCUR IN MEASURED DISTANCE FROM THE MIDPOINT OF CORTICAL BONE SURFACE?				
9. WHAT IS THE BONE DIAMETER?				
WHAT IS THE WIDTH OF THE BLADE AT THE SHARP EDGE?				
WHAT IS THE WIDTH OF THE BLADE AT THE BLUNT EDGE?				
C. ADDITIONAL OBSERVATIONS ON BACK				

Results

The independent scoring of a first round of observations by three observers is provided in Table 2 and it provides a basis for judging interpersonal interpretive error. After a reconsideration and discussion of individual cases, we summarized the major characteristics of the wounds resulting from the three weapon types in Table 4. We found that cleaver wounds were characterized by very recognizable entry sites in all cases (Table 2). With very few exceptions, all cases of cleaver trauma exhibited a clean entry, generally narrow and approximately 1.5 mm wide at the midpoint, with a smooth cut surface on the obtuse-angled side and fracturing on the acute-angled side (Fig. 2). This appearance conforms to the observations of Wenham (12). Cleaver wounds never resulted in radiating fractures at the entry site but did occur sometimes originating from the kerf floor (the *kerf* is the groove made by a cutting tool; the *kerf floor* is the termination point of the tool cut) (Fig. 3). Small pieces (0.5 cm and smaller) of fractured bone (Fig. 3) or feathered areas of bone (Fig. 4) were, however, sometimes pushed up on the acute-angled

TABLE 4—*Summary of entry and exit characteristics of three weapon types.*

Characteristic	Cleaver	Machete	Axe
Entry site recognition	Clearly recognizable	Less clearly recognizable	Sometimes clearly recognizable
Entry site appearance	Clean	Clean, Chattering	Clean, Chattering, Crushing, Fracture
Width of entry site	Narrow; approx. 1.5 mm	Medium; approx. 3.5 mm	Medium to large; approx. 4–5 mm
Fractures at entry site	Never	Most commonly originate past entry site at kerf floor on obtuse-angled side; several fragments	Originate at entry site; extend outward; large pieces of bone pushed into entry
Depth of penetration due to cut	Perpendicular cuts never penetrated entire bone	Rarely penetrated entire bone; mean penetration was 31.5% of bone diameter	Rarely penetrated entire bone; mean penetration was 14.2% of bone diameter
Exit site recognition	No exit sites	Clearly recognizable	Clearly recognizable
Exit site appearance and fractures	No exit sites	Fractures with several small to medium bone fragments	Fractures with large triangular bone fragments (often only one)

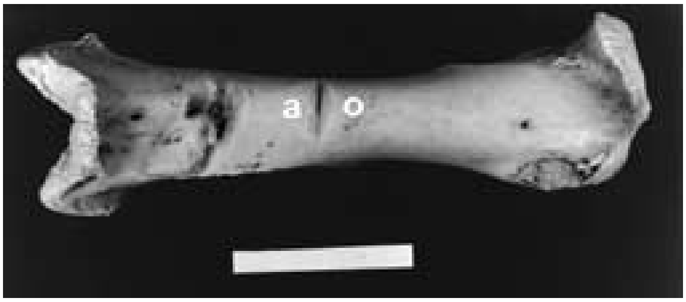

FIG. 2—*Typical perpendicular cleaver wound (right) showing smooth obtuse-angled side* (o) *and fractured acute-angled side* (a) *at site of weapon entrance. The wound on the left is a slightly oblique directed wound showing the same characteristics. Specimen 3 b. Bar = 5 cm.*

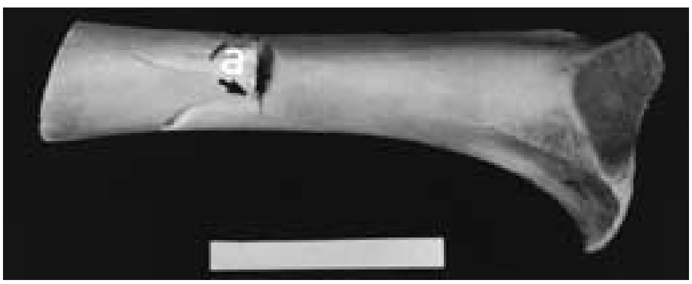

FIG. 3—*Perpendicular cleaver wound showing small pieces of fractured bone on acute-angled side* (a) *of the wound. Note the fracture originating from the kerf floor (arrow). Specimen 2 A. Bar = 5 cm.*

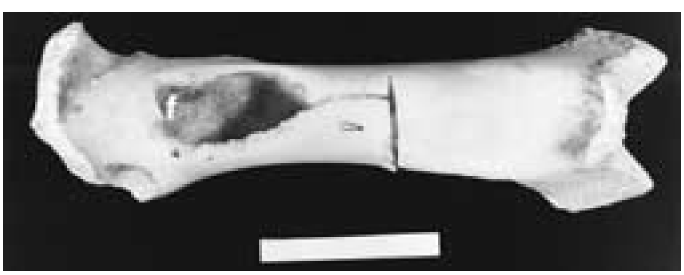

FIG. 4—*Typical perpendicular cleaver wound (right) showing an average distance of weapon penetration. Note that the oblique wound (left) results in a longer smooth cut area ending in typical fracture* (f) *at the exit area. Specimen 1 A. Bar = 5 cm.*

side; this rarely happened with the machete and never with the axe. Cleaver cuts perpendicular to the long axis of the bone never penetrated the entire diameter of the element and ended in a kerf floor (Figs. 2–4; Table 2). Striations are oriented parallel to the direction of the blade, in other words perpendicular to the kerf floor as noted by Symes et al. (11). In contrast, slicing striations such as those left by saws or knives are oriented parallel to the kerf floor. Cleaver cuts penetrated the bone a mean distance of 5.31 mm ($n = 9$) or 20.3% of the bone diameter. Because the cleavers never penetrated through the entire bone or resulted in exit fractures, no exit characteristics were observed.

We found that machete wounds were characterized by entry sites that were a little less clearly recognizable than those for the cleaver, but were recognizable. In most cases, the entry site exhibited an appearance of clean entry, and in several cases, chattering (Fig. 5). The width of the entry wound at the midpoint was medium, approximately 3.5 mm. Fractures often occurred originating at the kerf floor on the obtuse-angled side. There were often several bone fragments associated with these fractures (Fig. 6). Machete cuts penetrated through the bone a mean distance of 7.96 mm ($n = 7$) or 31.5% of the bone diameter. Exit sites were clearly recognizable and almost always characterized by fractures. Several small (0.5 cm

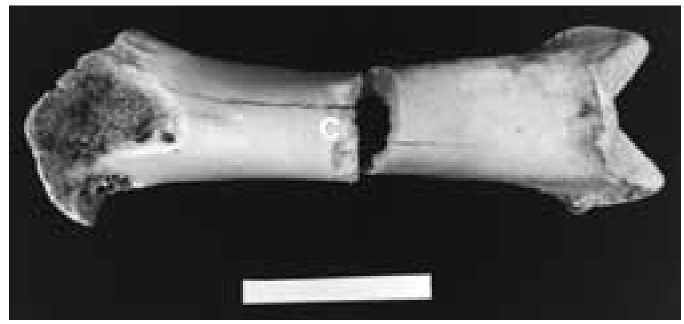

FIG. 5—*Typical perpendicular machete wound showing chattering and fracture originating at entrance site* (c). *Specimen 1 A. Bar = 5 cm.*

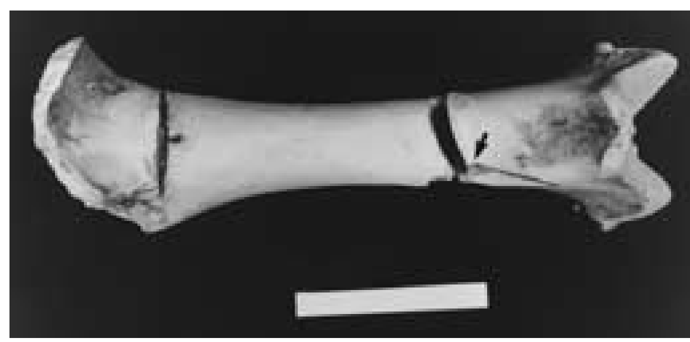

FIG. 6—*Slightly oblique machete wound (right) showing wide entrance site and fracture originating from kerf floor (arrow). The wound on the left is a perpendicular wound. Specimen 3 B. Bar = 5 cm.*

FIG. 7—*Perpendicular machete wound (right) illustrating extreme fracture relatively common in machete wounds perpendicular to long axis of element. The wound on the left is an oblique directed wound. Specimen 1 C. Bar = 5 cm.*

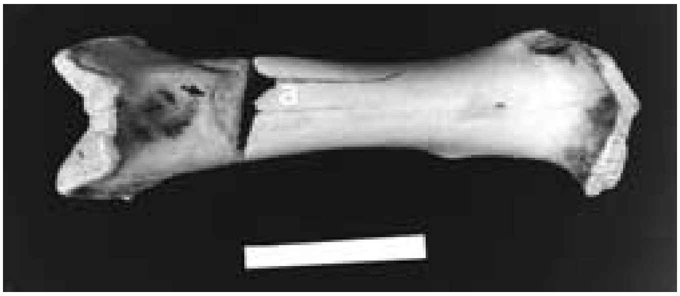

FIG. 8—*Perpendicular axe wound showing large wedge at entry site and fracture extending several centimeters from acute-angled side of wound* (a). *Note large piece of bone pushed inward from blow at obtuse-angled side (arrow). Specimen 1 A. Bar = 5 cm.*

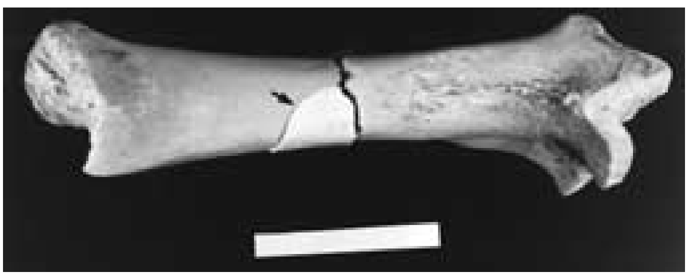

FIG. 9—*Perpendicular axe wound showing triangular piece of bone at exit side of wound (arrow). Specimen 2 C. Bar = 5 cm.*

or smaller) to medium (1.5 cm) pieces of fractured bone were common on the exit side of machete wounds.

We found that axe wounds were characterized by entry sites that were clearly recognizable, but axe entry sites exhibited variable appearance that consisted of clean entry, chattering, crushing, and fractures (Figs. 7, 8). The width of the entry wound at the midpoint was medium to large, approximately 4 to 5 mm. Often immediate fractures occurred at the site of entry (30 to 40% of cases observed). Fractures extended in some cases for several centimeters from the acute-angled side of the wound. Large pieces of bone (1.5 cm to 3 cm) were sometimes pushed in at the entry site (Figs. 7, 8); this was not seen in either cleaver or machete entry wounds. Axe cuts penetrated the bone a mean distance of 5.53 mm ($n = 6$) or 14.2% of the bone diameter. Exit sites were usually clearly recognizable and almost always characterized by fractures with large triangular bone fragments (often only one) on the exit side of the wound (Fig. 9).

Conclusions

Although general agreement about weapon type that caused a particular wound was present among the observers, more consistent interobserver agreement of the exact type of injury was found for sharper weapons such as the cleaver than for the axe due to less crushing and fracturing. In general, cleaver wounds had a distinctive appearance with narrow, sharp entrance wounds. Axes had a crushed and fragmented appearance occasionally exhibiting a wedge shape at the entry wound. Machetes were in between the two types of entry wound appearance. For all weapon types, entry and exit of the wound were often clearly apparent. Comparatively, each weapon presents us with enough criteria to make a reasonable judgment as to which was used. The lack of fracturing and crushing of cleaver wounds easily distinguishes them from axe wounds. A very good case can also be made for penetration depth as the deciding factor between a choice of cleaver or machete, with other factors such as width of penetration point and relative amount of fracturing at the floor compensating for differences in force of the blow. While some difficulty was experienced when comparing axe to machete, the overall crushing ability of the axe at the entry point as well as the shallow depth of penetration before fracturing as compared to the machete, does distinguish axe wounds in almost all observed cases. As observed in our experiment, width of the weapon wedge does affect the distance that the weapon moves through the bone before fracture, but the cleaver rarely attained the point of fracture and usually did not complete its passage through the bone.

There are some potential considerations for use of the information presented in this study in forensic contexts. The experiments were conducted using two male protagonists and one female protagonist, but no control was placed on which sex produced particular blows. Although the influence of sex on the force and direction of the blows was considered at the time of the experiment, we perceived that several other variables of the perpetrator could also influence the force and direction of blows such as handedness, rage, handicap, strength, body size, nutrition, and disease. We concluded that control of these multiple variables significantly affected what little control we could add by including sex of the perpetrator in our considerations.

Undoubtedly, there are some conditions we were not able to adequately address. For instance, as we described for our pilot study, we initially tried to examine the influence of the element placed on a hard surface as compared to one held in the air by one of us, but the wounds produced during suspension were not deep enough for adequate observation. The element held in the air was not the same as one articulated with the rest of the body, and when struck by the weapon did not offer the same resistance as it would if it had been articulated. Consequently, we abandoned this particular trial in our second round of experiments. Nonetheless, the position of body during attack would undoubtedly exert some influence on the eventual appearance of the wounds. In that regard, the observations derived from our experiments are most accurately used in situations where the blows were directed at an element on a hard substrate, such as a person lying down, rather than a situation where a person is standing.

Bone damage caused by sharp instruments is often encountered in forensic contexts, and recognizing the cause can be difficult. Damage from metal weapons must often be differentiated from that caused by other tools such as mower blades (4) or boat propellers (21). Experimental damage caused by metal implements is essential for establishing the replicability of particular types of damage to bone and predictable assessments in forensic cases. By and large, we found it to be possible to use macroscopic observation of the trauma inflicted on the bone by cleavers, machetes, and axes to make a reasonable estimate of weapon type that caused particular wounds.

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