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## TECHNICAL NOTE

*Kalan S. Lynn,*[1] *B.Sc. (Hons.) and Scott I. Fairgrieve,*[1] *Ph.D.*

# Macroscopic Analysis of Axe and Hatchet Trauma in Fleshed and Defleshed Mammalian Long Bones*

**ABSTRACT:** Recently, the authors have noted that many studies involving the characterization of chopping weapon wounds have used either semi-fleshed or defleshed bones (e.g., *J Forensic Sci* 2001; 46: 228). As these types of specimens do not reflect the full range of actual cases of postmortem dismemberment or perimortem trauma, 11 fresh pig (*Sus scrofa*) articulated hind limbs, with contiguous surrounding flesh, were inflicted with wounds using two axes and two hatchets. Defleshed humeri and femora were subjected to the same treatment. While there were no great differences found between the fleshed and defleshed specimens, characteristics observed including entrance site width and the presence of chattering were inconsistent with some aspects of Humphrey and Hutchinson's study (*J Forensic Sci* 2001; 46: 228). Further, it was found that curve transverse and spiral fractures were prevalent in femora, while longitudinal fractures were prevalent in fibulae. Hence, fracture types may play a role in characterizing some wounds caused by chopping weapons.

**KEYWORDS:** forensic science, forensic anthropology, trauma, axe wounds, hatchet wounds, bone fractures, chopping

The current literature contains a plethora of information on sharp force trauma to bone (1–15). The difficulty with this literature lies in the specimens used to test the effects of chopping weapons such as axes and hatchets. Research previously conducted on the effects of sharp force trauma to bone have centered predominantly on knives (2–9,14) and saws (3,8,12,13). Even though the most frequent method of homicide in Canada in 2006 was by stabbing (16), the use of axes and other hacking weapons is anecdotally related in media reports but not specifically noted in homicide statistics. Trauma studies using axes and hatchets have used either semi-fleshed or completely defleshed bone (1,2,15). Yet, these studies do not necessarily replicate the actual conditions in cases of perimortem hacking trauma or postmortem dismemberment.

Traumatic fractures are the result of an external, dynamic stress imparted to the bone until the strain becomes too great for the bone to withstand. When a mechanical stress is applied, the bone may return to its original condition if the stress is removed before the limits of elasticity have been exceeded. However, if the bone exceeds these limits, it enters a stage of plastic deformation and cannot return to its original condition. Structural failure occurs when the imposed stress continues to be applied past a yield point and the bone's integrity is breeched, reaching a point of failure. As this mechanism is true for all fracture types, it is necessary to examine the various types of stresses that may be imparted onto bone and the resulting fractures.

The direction in which a stress impacts bone dictates the type of fracture and may be one of five directions: tension, compression, torsion, bending, and shearing forces (17). Tension forces are those that pull on bone and are common in dislocations, resulting in few fracture lines, while compression forces are those directed downward onto bone. It is the hydroxyapatite crystals in bone that resist these types of forces, yet if the force is too great for the bone to resist, complete or incomplete discontinuities and/or fracture lines may result. Torsion forces are those that cause bone to twist while one end of the bone is held immobile, and result in fractures that spiral down the bone shaft, most often seen in accidents such as falls. Bending forces, as the name suggests, are forces that impact the side of the bone, causing it to bend and result in a break. Finally, shearing forces also involve an impact to the side of the bone in addition to the immobilization of one area of the bone. Fractures from these types of forces occur in dismemberment cases where one hand is used to hold a long bone in place and the other is used to dismember the body using an instrument such as a saw or knife.

In addition to the direction of force, the speed and focus of the force also influence bone injuries. In the case of speed, a force may either be static or dynamic. Static forces involve those which are applied at nearly a constant pressure over a longer period of time (e.g., weight-bearing), while dynamic forces involve a sudden application of force delivered at a high speed (e.g., gunshot wound). Dynamic forces are most commonly seen in forensic cases and will be the type of force demonstrated in our study. A force may be applied over a larger surface area, having a wide focus. Forces with a wide focus are found to have many fractures over a large area (e.g., a hammer impact vs. an axe impact). A force may also be applied to a single point, having a narrow focus to a point or a thin line, as in the case of cutting or chopping weapons such as axes (17).

Sharp force trauma entails the combination of a compression or shearing force that is applied dynamically with a narrow focus. This may include actions, such as puncturing, cutting, chopping, sawing, or crushing (18), and features, such as incisions, notches, striations, and fragmenting (wastage). Fracture morphology not only

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[1] Department of Forensic Science, Forensic Osteology Laboratory, Laurentian University, Ramsey Lake Road, Sudbury, Ontario P3E 2C6, Canada.

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depends on the biomechanical properties of the bone being hit but also on the characteristics of the causative weapon. Implements which are used for short strokes and jabs, such as knives, may be categorized as short-light weapons, with the majority of the force coming from the attacker's body (18). These implements would typically result in a V-shaped wound (18,19). In the case of long-heavy weapons, both hands are typically used, with the force coming from the large strokes which build momentum and result in a greater amount of kinetic energy (18). Additionally, as long-heavy weapons have tapering edges, their cuts tend to be V-shaped in cross-section yet much wider than those of light weapons such as knives (19). This category would include larger weapons such as machetes, swords, and axes, and would also be referred to as chopping weapons. Weapons such as hatchets and cleavers fall in between these two categories due to their size and how the energy is acquired before it is transmitted to the target, yet the defects they leave in bone are most consistent with chopping weapons (18).

Recent studies have concentrated on addressing the general nature of axe wound descriptions. In 2001, a study conducted by Humphrey and Hutchinson (1) examined hacking trauma caused by three machetes, cleavers, and axes on 28 moderately fleshed and severed lower pig limbs. Their macroscopic analysis found that axe wounds were clearly recognizable but variable, having a clean entry with chattering, crushing, and fractures, some of which were several centimeters long on the acute-angled side of the wound. Wound entry sites also sometimes exhibited a wedge-shaped appearance with large pieces of bone occasionally pushed in. Exit sites almost always had fractures with large triangular fragments of bone detaching from the opposite side of the wound. Finally, axe wounds could be differentiated from machete wounds based on the shallow depth of penetration before fracturing.

As the vast majority of studies are conducted on defleshed bone which would not replicate actual conditions in many forensic cases, the focus of this study was to determine the effect of overlying flesh on bone compared with defleshed bone when investigating chopping trauma.

## Materials and Methods

Eleven fully fleshed juvenile domestic pig (*Sus scrofa*) hind limbs and nine defleshed domestic pig bones were utilized in this study. Each fleshed hind limb contained a fully intact epidermal layer in addition to a femur, tibia, and fibula in articulation. The defleshed domestic pig long bones consisted of six defleshed humeri in addition to three defleshed femora with contiguous periosteum and minimal residual flesh. These defleshed specimens were frozen then thawed prior to use.

### *Implements*

The implements used to inflict wounds included two used axes, one used hatchet, and one newly purchased unused hatchet (Fig. 1). Axe 1 was much sharper than Axe 2 and slightly rusted. Axe 2 had a history of use for wood chopping and had a very dull and rusted blade. The blade on Hatchet 1 was also sharp yet not as sharp as Hatchet 2 and slightly rusted. Finally, Hatchet 2 was newly purchased for this study and had a very sharp blade, lacking rust. None of the blades were sharpened for our study. Note that sharpness scoring was based on the degree to which the implement blade caught on the dermal ridges of the thumb when carefully running it across the blade.

FIG. 1—*Implements used for trauma infliction. From top to bottom: Axe 1, Axe 2, Hatchet 1, and Hatchet 2. (Photo by K. Lynn)*

A trauma infliction station was set up using a section of drywall and placed flat on the floor in our laboratory. This was primarily carried out to provide an aid in preventing the implements used from damaging the underlying floor when inflicting trauma.

### *Trauma Infliction*

Each hind limb was placed lateral side up on the trauma infliction station in the center of the drywall. The tissue thickness was measured using a fine needle probe to penetrate the epidermis, dermis, and hypodermis, and a ruler was used to determine the depth the probe traveled before the underlying bone was reached. This depth was intended to represent the estimated tissue depth found in a human lower limb. In the case of each femur, the tissue thickness was measured directly after trauma infliction by inserting the ruler directly into the wound.

A wound was then inflicted to the lateral femur in addition to either the lateral fibula or medial tibia using one of the four implements. As much force as possible was used on each femur, while slightly less force was used on the tibiae and fibulae in order to prevent penetration of the blade into the underlying floor. Several hits were required for most femora in order to penetrate the epidermal layer which was especially true when using Axe 2 due to its dull blade. Several hits were also required when the implement merely skimmed the bone in order to ensure an adequate impact site. It is important to note that fleshed hind limb 1 was initially used as a test subject for each step of the process. The distribution of wounds inflicted according to weapon type and bone is summarized in Table 1. Some lateral aspects of tibiae were inflicted with trauma as the implements penetrated beyond the fibulae.

The defleshed specimens were inflicted with a wound on either the lateral or medial surface, using as much force as possible when using each implement. The distribution of wounds inflicted according to weapon type on defleshed bones is also summarized in Table 1.

### *Sample Preparation*

Tissue was removed from the fleshed specimens using a large kitchen knife, tissue scissors, and a scalpel, being careful not to nick the bones. Previously fleshed as well as defleshed specimens were then boiled in water for *c.* 4 h. Once the boiling process was

TABLE 1—*Inventory of inflicted trauma on fleshed and defleshed bones according to weapon type.*

| | Axe 1 | Axe 2 | Hatchet 1 | Hatchet 2 | Totals |
|---|---|---|---|---|---|
| Fleshed | | | | | |
| Femora | 3 | 3 | 2 | 3 | 11 |
| Tibiae | 3 | 1 | 1 | 3 | 8 |
| Fibulae | 2 | 2 | 2 | 2 | 8 |
| Totals | 8 | 6 | 5 | 8 | 27 |
| Defleshed | | | | | |
| Humeri | 2 | 2 | 2 | 1 | 7 |
| Femora | 0 | 1 | 1 | 1 | 2 |
| Totals | 2 | 2 | 3 | 2 | 9 |

TABLE 2—*Prevalence of bisection in fleshed and defleshed skeletal elements according to implement.*

| | Axe 1 | Axe 2 | Hatchet 1 | Hatchet 2 | Totals |
|---|---|---|---|---|---|
| Fleshed | | | | | |
| Femora | 3/3 | 3/3 | 0/2 | 2/3 | 8/11 (72.7%) |
| Tibiae | 0/3 | 0/1 | 0/1 | 0/3 | 0/8 (0%) |
| Fibulae | 2/2 | 2/2 | 2/2 | 2/2 | 8/8 (100%) |
| Totals | 5/8 | 5/6 | 2/5 | 4/8 | 16/27 (59.3%) |
| Defleshed | | | | | |
| Humeri | 2/2 | 2/2 | 1/1 | 0/1 | 5/6 (83.3%) |
| Femora | 0/0 | 0/1 | 1/1 | 1/1 | 2/3 (66.7%) |
| Totals | 2/2 | 2/3 | 2/2 | 1/2 | 7/9 (77.8%) |

completed, the residual flesh was removed manually and using a scalpel.

Using a one-eighth inch drill bit, the shaft of each long bone was drilled on each end into the medullary cavity except in the case of bones that were bisected near the epiphysis where only one hole was drilled. Each specimen was injected with a solution of either 30% hydrogen peroxide (for fleshed specimens) or 3% hydrogen peroxide (for defleshed specimens). Each bone and associated bone fragments were soaked in hydrogen peroxide for *c.* 22 h in order for them to bleach and to allow any remaining cartilage to be softened and removed more easily. Bones were allowed to soak for no more than 24 h as soaking for any longer would cause the hydrogen peroxide to corrode and thin the cortices of the bones. After the soaking period, the bones were removed from the hydrogen peroxide solution and any softened cartilage was removed using a scalpel. The bones were then rinsed with clean tap water and the peroxide solution was removed from the medullary cavities using the syringe. These cavities were then rinsed out with clean tap water and the specimens were allowed to dry.

### *Macroscopic Analysis*

All wounds and associated fractures were examined macroscopically. Stereomicroscopy was used on a limited basis and only to aid in visualizing the margins of the impact sites and fractures in addition to the presence of flaking. Our observations made in the macroscopic analysis included the width of entry sites, noting if they exhibited chattering and fracturing, as per Humphrey and Hutchinson (1). We also observed the length of entry sites. In addition, the prevalence of bisection, types of fractures, and flaking on acute- and obtuse-angled sides of the kerf was also noted. Unlike Humphrey and Hutchinson (1), the present study did not note the depth of the wounds as this was dependent upon the amount of force used (which was not standardized in this case) and as bones were bisected in most cases anyway. When possible, the kerf widths and lengths were measured using sliding calipers.

As sample sizes here were small, dividing specimens up according to bone type and weapon used necessitated expressing our results as simple fractions and percentages. The presence of each feature noted above was indicated, and the mean entry site widths and lengths were calculated in addition to their standard deviations.

## Results

All of the femora impacted by either axe were bisected while none of those impacted by Hatchet 1 were bisected and two out of three femora inflicted with trauma by Hatchet 2 were bisected. Hence, eight out of 11 or 72.7% of fleshed femora were bisected. All eight tibiae remained intact regardless of the implement used while all eight fibulae were bisected with a total of 16/27 or 59.3% of fleshed bones bisected (Table 2). All but one of the six defleshed humeri were bisected while two out of the three femora were bisected, with Hatchet 2 and Axe 2 being unable to bisect the bones, respectively. In total, seven out of nine or 77.8% of the bones were bisected.

Chattering was also examined in the fleshed and defleshed specimens. This fragmentation was exhibited by eight out of 11 fleshed femora, none of the tibiae, and five of eight fibulae (Fig. 2). In total, 13/27 (48%) fleshed bones were found to exhibit chattering, which appears to contradict the findings of Humphrey and Hutchinson (1) that most axe wounds exhibited chattering (Table 3). Meanwhile, four out of nine (44.4%) defleshed specimens were found to exhibit chattering, also inconsistent with their findings (Table 3).

When examining the acute- and obtuse-angled sides of the kerfs on fleshed specimens, it was discovered that 100% (seven out of seven) of the femora and 100% (eight out of eight) of the tibiae exhibited flaking on their acute sites, while two out of seven femora and none of eight tibiae exhibited flaking on their obtuse sides (Fig. 3), corroborating Wenham's (20) findings. Despite this, all four fibulae had a lack of flaking on either acute or obtuse sides. With defleshed bones, however, all six with intact impact sites were found to have flaking on their acute-angled sides and all but one exhibited a lack of this characteristic on the obtuse-angled side.

Table 4 presents the lengths and widths of fleshed femora and tibiae entry sites. It is of interest to note that the femora have a mean length of 21.1 mm while tibiae have a mean width of 6.2 mm. The tibiae entry sites had a considerably smaller mean length of 9 mm and a much smaller mean width of 1.7 mm. The defleshed femora were found to have entry site lengths similar to those of the fleshed femora at 21.8 mm (Table 4). The mean widths, however, were much smaller, having a value of 2.8 mm.

FIG. 2—*Chattering on a previously fleshed femur. (Photo by K. Lynn)*

TABLE 3—*Prevalence of chattering in fleshed and defleshed skeletal elements according to implement.*

| | Axe 1 | Axe 2 | Hatchet 1 | Hatchet 2 | Totals |
|---|---|---|---|---|---|
| Fleshed | | | | | |
| Femora | 3/3 | 3/3 | 0/2 | 2/3 | 8/11 (72.7%) |
| Tibiae | 0/3 | 0/1 | 0/1 | 0/3 | 0/8 (0%) |
| Fibulae | 2/2 | 0/2 | 1/2 | 2/2 | 5/8 (62.5%) |
| Totals | 5/8 | 3/6 | 1/5 | 4/8 | 13/27 (48.1%) |
| Defleshed | | | | | |
| Humeri | 1/2 | 1/2 | 0/1 | 0/1 | 2/6 (33.3%) |
| Femora | 0/0 | 0/1 | 1/1 | 1/1 | 2/3 (66.7%) |
| Totals | 1/2 | 1/3 | 1/2 | 1/2 | 4/9 (44.4%) |

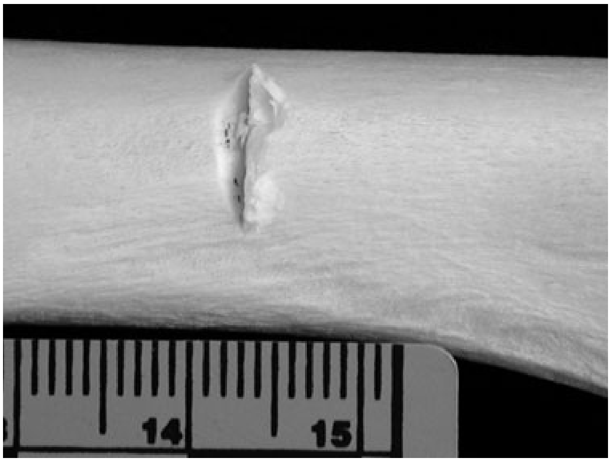

FIG. 3—*Axe wound on a tibial shaft with an absence of flaking on the obtuse-angled side (left) and flaking on the acute-angled side (right). (Photo by K. Lynn)*

TABLE 4—*Entry site lengths and widths on fleshed and defleshed skeletal elements.*

| | Femora | | Tibiae | | Humeri | |
|---|---|---|---|---|---|---|
| | Length (mm) | Width (mm) | Length (mm) | Width (mm) | Length (mm) | Width (mm) |
| Fleshed | 14 | 1.5 | – | – | – | – |
| | 33 | – | 7 | 1 | – | – |
| | 15.5 | 8 | 8 | 1 | – | – |
| | 22 | 9 | 12 | 3 | – | – |
| Mean | 21.1 | 6.2 | 9 | 1.7 | – | – |
| $\sigma^2$ | 8.6 | 4.1 | 2.6 | 1.2 | – | – |
| Defleshed | – | – | – | – | 23 | 7 |
| | – | – | – | – | 14 | 4 |
| | 23 | 2.5 | – | – | 18 | 1.5 |
| | 20.5 | 3 | – | – | 22 | 6 |
| Mean | 21.8 | 2.8 | – | – | 19.3 | 4.6 |
| $\sigma^2$ | 1.8 | 0.4 | – | – | 4.1 | 2.4 |

Due to bisection and extensive fragmentation, measurements for fibulae and several other specimens were unable to be obtained.

The defleshed humeri were found to vary much more, having a mean entry site length similar to those of the femora with a value of 19.3 mm. Their mean width of 4.6 mm was equally variable, varying between 1.5 and 7 mm. All mean entry site widths, except for that of the defleshed humeri, extended the range of 4 mm to 5 mm obtained by Humphrey and Hutchinson (1).

The presence of five different fracture types on the fleshed femora was also noted and scored as either present or absent (Table 5).

TABLE 5—*Presence of different fracture types on fleshed femora inflicted with trauma according to implement.*

| | | Transverse | | Longitudinal | | |
|---|---|---|---|---|---|---|
| Specimen number | Implement | Straight | Curve | Impact site | Nonimpact site | Spiral |
| P1 | A1 | | ✓ | | | |
| P3 | H1 | | | ✓ | | ✓ |
| P4 | H1 | | | ✓ | | ✓ |
| P5 | H2 | | | | | |
| P6 | H2 | | | | | ✓ |
| P7 | A1 | | ✓ | | ✓ | |
| P8 | A2 | | ✓ | | | |
| P9 | A2 | | ✓ | ✓ | ✓ | ✓ |
| P10 | A1 | ✓ | ✓ | ✓ | | |
| P11 | A2 | | | | ✓ | ✓ |
| P12 | H2 | | ✓ | | | |

A positive indication is scored as present (✓).

FIG. 4—*Spiral fractures on two previously fleshed femora. (Photo by K. Lynn)*

Each type of fracture was seen on at least one occasion, with the presence of curve transverse fractures occurring in six of 11 femora, and with spiral fractures being the second most common, occurring in five of 11 femora (Fig. 4). Conversely, straight transverse fractures were only seen in hind limb 10 where Axe 1 was the causative implement. In the fleshed tibiae, it is interesting to note that fractures were only present on two occasions; a longitudinal fracture emanating from an impact site inflicted by Axe 1 and a straight transverse fracture found on the proximal tibia of hind limb 12. This second fracture emanated from a wound caused by Hatchet 2 (Table 6). In the fleshed fibulae, the predominant fracture type was the longitudinal fracture which originated from the impact site, occurring on five occasions, and the spiral fracture, only occurring once where trauma was delivered by Hatchet 2 (Table 6).

In the defleshed specimens, curve transverse, spiral, and longitudinal fractures originating from the impact site were seen approximately half of the time (Fig. 5). It is interesting to note, however, that straight transverse fractures were not seen at all. Further, a longitudinal fracture not originating from the impact site was seen in only one defleshed femur but in three fleshed femora.

TABLE 6—*Presence of different fracture types on fleshed fibulae and tibiae inflicted with trauma according to implement.*

| | | | Transverse | | Longitudinal | | |
|---|---|---|---|---|---|---|---|
| Element | Specimen number | Implement | Straight | Curve | Impact site | Nonimpact site | Spiral |
| Fibula | P1 | A1 | ✔ | | ✔ | | |
| | P3 | H1 | ✔ | | ✔ | | |
| | P4 | H1 | | ✔ | | | |
| | P5 | H2 | | | ✔ | | ✔ |
| | P6 | H2 | ✔ | | ✔ | | |
| | P7 | A1 | | | | | |
| | P8 prox. | A2 | | ✔ | ✔ | | |
| | P8 dist. | A2 | | ✔ | | | |
| Tibia | P5 | H2 | | | | | |
| | P6 | H2 | | | | | |
| | P7 | A1 | | | ✔ | | |
| | P9 | A2 | | | | | |
| | P10 | A1 | | | | | |
| | P11 | H1 | | | | | |
| | P12 prox. | H2 | ✔ | | | | |
| | P12 dist. | A1 | | | | | |

A positive indication is scored as present (✔).

## Discussion

While bisection was seen in 16 out of 27 fleshed specimens (59.3%) and in seven of nine defleshed specimens (77.8%), this feature was dependent upon the amount of force used and should only be used in order to put other observations into perspective. Initial observations included the fact that bisection occurred more easily and required fewer blows in the defleshed specimens, suggesting that the flesh absorbed some of the energy of the impact, as noted by Alunni-Perret et al. (2), thus causing the fleshed specimens to be less likely to bisect.

As chattering was seen in 48.1% of fleshed elements and not in the majority of moderately fleshed cases as observed by Humphrey and Hutchinson (1), this may provide further evidence to the shock absorbing capacity of the contiguous flesh. Despite this, such a low percentage was obtained as none of the eight tibiae inflicted with wounds exhibited chattering. This was most likely due to the fact that three of these bones were impacted after the implements penetrated fibulae, causing some of the impact to be attenuated by the time the tibiae were hit. When considering only femora and fibulae, chattering occurred 68% of the time (13/19 times), a consistency with Humphrey and Hutchinson's (1) findings. Although the defleshed bones in our study responded in a fashion inconsistent with Humphrey and Hutchinson's (1) findings, they were consistent with the overall prevalence of chattering in our fleshed specimens.

In 1989, Wenham (20) discussed the presence of flaking and fracturing on the acute-angled side of cut marks which was corroborated by the findings in our defleshed specimens. Despite this, while all six defleshed specimens with intact impact sites exhibited flaking on their acute-angled sides, only 78.9% of the acute-angled sides of the fleshed specimens exhibited flaking. Although this prevalence (15 out of 19) was relatively high, it may not be adequate for court purposes to suggest the angle of impact and position of the offender. While these concerns are valid, it must be noted that none of the four fibulae exhibited flaking on their acute-angled sides, most likely due to extreme fragmentation on their impact sites. Removing these four elements from the sample of fleshed bones, however, increased the prevalence of flaking on acute-angled sides to 100%. In regards to the obtuse-angled sides, two out of 19 fleshed elements and one out of six defleshed elements were found to exhibit flaking at this location. While it would be expected to see no flaking from the observations of Wenham (20) and Humphrey and Hutchinson (1), flaking was seen on the acute-angled side each time it was seen on the opposite side. This indicated that although it may be difficult to determine the angle of impact in instances where there was much damage at this location, there were no instances that would have led an observer to reach erroneous conclusions. That is, where there was flaking on the obtuse-angle side of the cut mark, there was flaking on the acute-angled side. The same applies in the defleshed bone where one out of six specimens exhibited flaking on its obtuse-angle side yet still exhibit flaking on its opposite side.

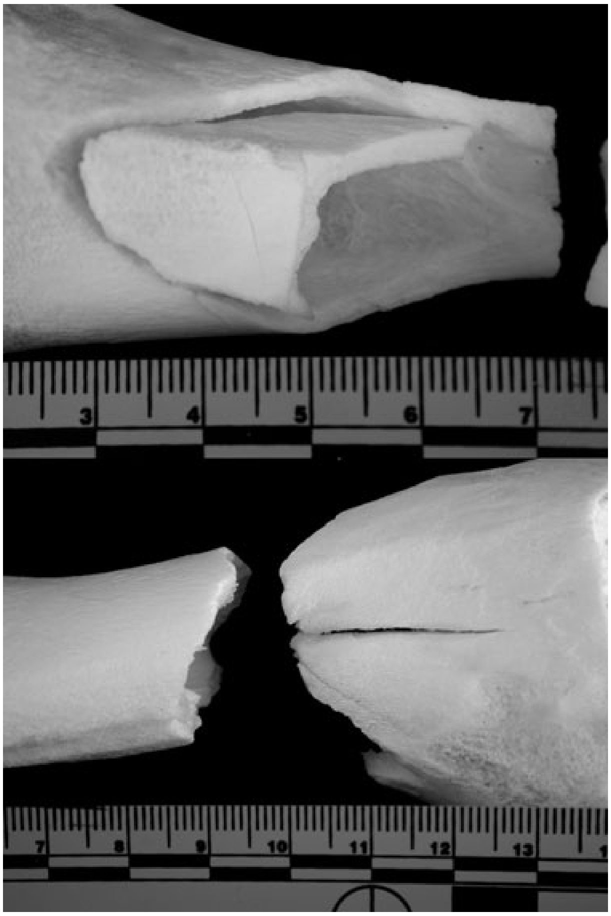

FIG. 5—*Spiral fracture on a defleshed femur (top) and a longitudinal fracture on a defleshed humerus (bottom). (Photo by K. Lynn)*

As Humphrey and Hutchinson (1) determined that axe wounds exhibited entry sites with a width of 4 to 5 mm, the present study's findings contradict this once again except in the case of the defleshed humeri. The fleshed femora were found to have a larger mean entry site width of 6.2 mm while the defleshed femora were found to have a much smaller width of 2.8 mm. The tibiae also had a lower mean entry site width of 1.7 mm while the humeri were within 4–5 mm (4.6 mm). While these differences may be attributed to differing weapon types, it is clear that there is no consistency in this measurement within our study when comparing fleshed with defleshed specimens, as well as between our study and that of Humphrey and Hutchinson (1). From this, it may only be possible to exclude an axe as being the causative implement in a case of a deep but very narrow cut mark caused by an implement such as a knife or scalpel. This is also true of the cut mark length which was much smaller in the fleshed tibiae (9 mm) when compared with those obtained in the fleshed and defleshed femora and defleshed humeri (21.1, 21.8, and 19.3 mm, respectively). Although these last three lengths were fairly consistent with one another, the full range of measurements is from 14 mm to 33 mm in the fleshed femora. Therefore, it may only be practical to determine the minimum length of the blade of the causative implement from these measurements.

As it is well known that axe wounds result in a great degree of fracturing, the presence of the different types of fractures were considered and scored as either present or absent. Counting the individual number of fractures would have proven to be very difficult due to the loss of small fragments and as many variables, such as force and the angle of impact, would influence these numbers. The predominant fracture type in the fleshed femora was the curve transverse fracture. This type of fracture was also associated with a bisection of the bone, resulting in an initial transverse fracture and leading to increased tensile and compressive forces (21). Next in prevalence was the spiral fracture, suggesting that when axes impact these bones, they cause the bones to twist at the point of greatest tension, resulting in this type of fracture. This would most likely be due to the sharp-blunt nature of the trauma, with the blade having the ability to wedge into the bone and cause torsional movement. These findings are reinforced by the defleshed femora where two of three exhibited spiral fractures. Longitudinal fractures originating from the impact sites were also prominent in the fleshed and defleshed specimens, most likely due to the wedge action of the blade and its ability to split the bone to a greater degree than other sharp weapons (19).

In the fleshed tibiae, only two fractures were observed in total. This may be due to the fact that three of the tibiae were inflicted with trauma after the overlying fibulae acted to attenuate the force and cause a lower-energy impact, resulting in less of the weapon blade from penetrating and less of a wedge action. In the fleshed fibulae, however, extensive fracturing resulted with longitudinal fractures emanating from the impact sites in five out of eight instances. This was most likely due to the implements penetrating these small bones completely, wedging the proximal and distal halves apart. Straight and curve transverse fractures were also observed in these bones as with the fleshed femora due to the bending action of the bone upon impact. This extensive bending would be due to the thickness of the blade and its sharp-blunt mechanism, resulting in the convex side of the bone being under great tension and the concave side under compression. Despite this, a low number of spiral fractures were produced, likely due to the flat structure of the fibulae which would more likely be bisected by transverse fractures before twisting to produce spiral fractures. Overall, it appears as though the bones must be analyzed separately due to their structure or the degree to which the weapon penetrated the bone. Despite this, no great differences were apparent between the fleshed femora and defleshed humeri.

Our research demonstrates the potential of using bisection and the presence of chattering and different fracture types to identify axe and hatchet wound trauma. An increased sample size may prove axe and hatchet wounds to be differentiable based on these characteristics. As this research only demonstrates that minimum blade widths and lengths may be determined from the measurements taken, it begs the question whether ranges can even be given due to the great variability involved in the blades of chopping weapons. By being able to corroborate the orientation at which an implement struck a bone through flaking (e.g., that the implement came from the direction of the proximal end of the bone and was angled toward the distal end upon impact), the position of the offender may be determined to elucidate details of the trauma. It would be important to keep in mind, however, that right-handed people tend to swing and angle an axe toward their left and vice versa for left-handed people. This point would need to be taken into consideration when the reconstruction of events takes place.

The ability to determine if specimens were fleshed or defleshed at the time a wound was inflicted is an issue that needs to be considered. Recently documented cases of dismemberment involving the removing or teasing away of flesh prior to the actual dismemberment have come to light (22).

There are several limitations to our study. First, although past research has determined that domestic pig bones closely approximate the hardness of human bones compared with other mammals, inherent differences still exist (12). For example, as domestic pig bones are known to be denser than human bones, pig bones may react in a different manner to trauma.

A second limitation of this study includes the numerous variables affecting fracture dynamics. As the amount of force was not standardized, slight variations in force may result in different observations. For example, if one hit on a fleshed femur was slightly lighter than that on a defleshed femur, this may have affected the types of resultant fractures. In addition, chattering as well as the number and types of fractures observed may have been affected by the amount of force used as opposed to the presence of overlying flesh.

Another inherent variable in this study is the variation in the angle of impact. Although it may not have significantly affected the overall results, the angle of impact does influence certain observations, including an increase in flaking on the acute side of the kerf, and may also have affected chattering and fracturing. Despite this, variations in strength and angle of impact are part of actual forensic casework, indicating that any conclusions made regarding axe and hatchet trauma should be independent of force and angle of impact.

Although the variation due to the different types of bone used was not completely investigated in this study, it would have had an effect on the results. For example, as fibulae are much more slender and less robust than other long bones such as femora, it would be expected that they would react differently to trauma such as by exhibiting different types of fractures and bisection in more instances. A study of the variation in the axe wound response characteristics of different skeletal elements would be beneficial.

As four different types of implements were used, this was yet another source of variation. As the initial goal of the project was to characterize trauma caused by different chopping weapons, two axes and two hatchets were obtained in order to begin this endeavor. Wenham (23) noted that the same axe produced wounds of varying appearances, leading to the conclusion that these wounds may only be able to be characterized in general terms.

## Summary and Conclusions

In the macroscopic analysis of axe and hatchet trauma, it was found that chattering occurred approximately half the time in fleshed and defleshed bones which is less often than stated by Humphrey and Hutchinson (1). Further, the use of flaking to determine angle of impact was found to be useful and consistent with the previous findings of Wenham (20), with the acute-angled side of the kerf exhibiting flaking and detachment of small fragments of bone. This finding was consistent in both fleshed and defleshed bone where the impact site was still evident (21). Our study found the entry site width to be variable, with some being smaller and others being much larger than the 4–5 mm range obtained by Humphrey and Hutchinson (1). As this variable not only depends on blade width but also on the force used, it does not appear to be useful in forensic contexts due to the range of variability involved. The same is also true of the variability in the entry site lengths. We found that a range of 14–33 mm for entry site lengths may only be useful to indicate the minimum length of the weapon's blade. When addressing the types of fractures seen, curve transverse and spiral fractures were predominant in fleshed and defleshed femora while longitudinal fractures were extensive in the fleshed fibulae.

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Additional information and reprint requests:
Scott I. Fairgrieve, Ph.D.
Department of Forensic Science
Laurentian University
935 Ramsey Lake Road
Sudbury, Ontario P3E 2C6
Canada
E-mail: sfairgrieve@laurentian.ca