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TECHNICAL NOTE

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Scanning Electron Microscopy Analysis of Experimental Bone Hacking Trauma

ABSTRACT: The authors report on their macro- and microscopy study of bone lesions made by a sharp force instrument (a single blade knife), and a sharp-blunt instrument classified as a chopping weapon (a hatchet). The aim of this work was to attempt to identify the instrument by analyzing the general class characteristics of the cuts. Each weapon was used on human bones. The results indicate that macroscopic analysis is more problematic. The microscopic analysis assessed that characteristics examined were effective in distinguishing sharp from sharp-blunt injury to the bone. The microscope facilitates analysis unachievable with macroscopic methods, some three-dimensional characteristics not visible to the naked eye being clearly defined with its use. Emphasis has been placed on the value of SEM as an anthropologist's tool in bone lesion injuries.

KEYWORDS: forensic science, forensic anthropology, bone trauma, scanning electron microscopy (SEM), implements, cut marks, tool marks.

The routine use of macroscopic observation of the lesion, in forensic trauma analysis of bones is common, whereas microscopic studies are rarely reported in the literature. Scanning electron microscopy (SEM) is a high-tech instrument that provides high-resolution three-dimensional surface images and an increased field of depth. It is commonly used in fields such as biology, geology, or medicine (1). Soft tissue trauma wounds have been studied by Rawson et al. (2). The analysis of marks from bullets is also well documented (3). SEM is also able to provide interesting clues from bone lesions that are not always visible to the naked eye, or with light microscopy (4). It has been used for analysis of surfaces of teeth (5), for the study of teeth according to eating habits or disorders (6,7), and in forensic anthropology for the analysis of burned bones (8) or burned teeth (9).

Some bone lesions are difficult to identify from macroscopic observation: the first step is to recognize a blunt, sharp or chopping bone injury; the second is to attempt to link the lesion with a specific implement. The first step is established by stating the class characteristics of the instrument, including the size and the general features of it (10). Humphrey et al. (11) experimentally studied bone trauma on pig bones, using machete, cleaver, and axe weapons. They concluded that the lesion made by the cleaver was easily identifiable, because the bone lesion was constantly thinner compared to the other weapons, and there were no radial fractures in the first case, in contrast to the others. The second step is to set up individual features of each weapon, in the same general class (12), particularly focusing on striae analysis from the surface of the injured bone (4). In forensic pathology or anthropology, this is particularly relevant in cases of postmortem dismemberment (13,14) or in homicide cases (15).

However, there are only a few cases reported in the literature, SEM analysis of forensic bone trauma is rarely reported on (11) and the experimental studies are mainly concerned with animal bones (4,11). Hence, our attempt to experiment on human bone lesions, macroscopically, and under SEM analysis. The aim was to study macroscopically and microscopically (SEM) the general characteristics of the bone lesion made by a sharp force instrument (a single blade knife), and sharp-blunt instrument (a hatchet), classified as a chopping weapon in order to identify the instrument (general class characteristics) from the observation of the bone lesion, which is an important goal in forensic practice. At the same time, we wanted to study the orientation of the blade at the moment of impact.

Material and Methods

This experimental study was performed on sections of human femurs. In order to comply with the ethical issue, the bones were taken from individuals who had "given their bodies to science" within a specific French law, which allows anatomical dissections, sampling and research. After removing the femurs, the bones were conventionally prepared by dissecting away the soft tissues, taking care not to alter the bone surface, and then boiling them in water.

The trauma was inflicted with a special device (Fig. 1). The weapon was set up on the central piston of this device, the kinetic

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FIG. 1—*The device used for delivering the blow.*

FIG. 2—*The knife used.*

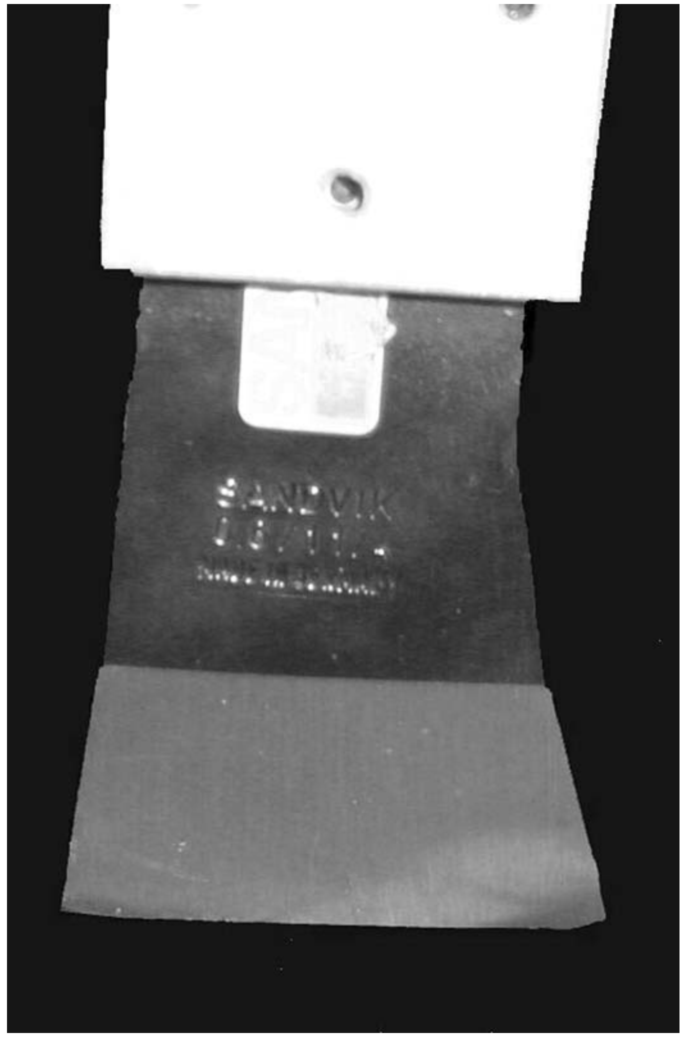

FIG. 3—*The hatchet used.*

energy was calibrated by the force of gravity: the force of the trauma being proportional to the height. Two weapons were used: a knife and a hatchet (Figs. 2 and 3). Three kinds of trauma were performed: one with the blade of a knife (15 samples), the second with the sharp part of the hatchet (15 samples) and the third kind of trauma was inflicted by the tip of the knife blade. This last trauma was done by hand, because it proved impossible to get a bone lesion with our device, even at the maximum height, the force was insufficient (15 samples). All these samples came from a female femur, divided into fragments. Then a small fragment that included the bone lesion was cut with an electric saw, in order to get a piece smaller than 1 cm square, capable of being studied under SEM.

Each lesion was initially evaluated macroscopically, by recording the general features of the lesion, and every detail visible to the naked eye. We described the shape, the edges, and the bone features visible near the edges of the lesion. We also determined if the orientation of the blow could be determined macroscopically when the tip of the blade was used.

Then each sample was coated with gold to facilitate the SEM analysis (JEOL JSM 5310 LV Scanning microscope). The SEM analysis included the features of the floor, the walls, and the edges of the lesion, the associated bone lesions near the edges, the features of the extremities, the presence of bone fragments near the edges and the orientation of the blow when the tip of the blade was used.

To compare the distribution of the lesion's characteristics between the knife and the hatchet, we used the chi square test and then appropriate, the Fisher's exact test. A 0,05 significant level was used to interpret the tests results.

Results

The bone lesions produced by the knife blade and the hatchet, were macroscopically almost identical (Table 1) exhibiting a linear and narrow lesion. The edges were more irregular with the hatchet than with the knife but the type of bone lesions exposed near the edges were identical with either a small depression or a light raising. The amount of raising was more significant in the knife sample and the amount of the macroscopic depression near the edges were more significant in the hatchet sample, but there were no significant differences statistically (Table 1). The bone lesions produced

TABLE 1—*Macroscopic analysis of the lesions due to the knife and the hatchet. Frequency of the main characteristics (Number of samples bracketed).*

	Knife ($N = 15$)	Hatchet ($N = 15$)	p	Tip of the blade ($N = 15$)
Shape	linear (15)	linear (15)	>0.05	rounded (15)
Aspect	narrow (15)	narrow (15)	>0.05	puncture (15)
Edges	even (15)	even (9)	<0.01	even (7)
		Irregular (6)		irregular (8)
Orientation of the blow				(4)
Adjacent bone lesions*				
	depression (6)	depression (9)	>0.05	raising (5)
	unilateral (15)	unilateral (7)		unilateral (15)
		bilateral (8)		
	raising (6)	raising (1)	>0.05	
	unilateral (15)	unilateral (7)		
		bilateral (8)		
	no lesion (3)	no lesion (5)	>0.05	

* : Near the edges.

TABLE 2—*Microscopic analysis of the lesions due to the knife and the hatchet. Frequency of the main characteristics (Number of samples bracketed).*

	Knife ($N = 15$)	Hatchet ($N = 15$)	p	Tip of the blade ($N = 15$)
Floor	even (15)	even (15)		even (10)
				irregular (5)
Walls	even (15)	even (15)		even (11)
				irregular (4)
Edge n°1	even (15)	irregular (15)	<0.01	irregular (15)
Edge n°2	even (3)	even (1)	>0.05	even (6)
	Irregular (12)	irregular (14)		irregular (9)
Adjacent bone lesions*				
	flakes and raising (12)	flakes (14)	>0.05	flakes (11)
	unilateral (14)	unilateral (8)	0.02	unilateral (4)
	bilateral (1)	bilateral (7)		bilateral (11)
Lateral pushing back				
	(0)	(15)	<0.01	(10)
		bilateral (11)		bilateral (11)
		unilateral (4)		unilateral (4)
Extremities	narrow (14)	narrow (4)	<0.01	
	square (1)	square (7)		
		square or narrow (4)		
Bone fragments	(6)	(9)	>0.05	(0)
Orientation of the blow				(14)

* : Near the edges.

by the tip of the blade were smaller puncture like. We macroscopically determined the exact orientation of the blow in only 4 samples.

Conversely, the SEM analysis showed interesting features in both the knife and the hatchet lesions (Table 2). Generally speaking, lesions caused by the knife blade were clean, the breadth being roughly the same along the whole length. The walls and the floor were all even. The first edge was very clean, while the second edge was often more irregular (Fig. 4), with a raising and flakes associated on the adjacent bone surface (Fig. 5). We did not see lateral pushing back in this sample (bone laterally compressed) but there were microscopic bone fragments into the lesion in 6 samples. The extremities were thin in the majority of cases.

The lesions caused by the hatchet exhibited other features. The width was roughly the same on the whole lesion. The walls and the floor were quite smooth. The edges were uneven, with a significant amount of flakes (pieces of bone removed during the bone percussion) and fractured bone on the bone adjacent cortex (Fig. 6). The presence of bone fragments was visible in the lesion in 9 samples. In all cases, we saw a lateral pushing back, bilateral in the majority of cases (Fig. 7). This lateral pushing back is a lateral compression. When the hatchet impacts the bone, the walls of the lesion are subject to an increasing compressive force until failure occurs, with a bone accumulation on adjacent surfaces of the lesion. The extremities were either square or square and thin.

The lesions caused by the tip of the blade were irregular, often having irregular edges with lateral pushing back on the bone (10 samples), on one or both sides (Table 2). One extremity of the lesion was wide, and the other one was very thin in 14 samples (Fig. 8). The walls and the floor were relatively clean. There were no adjacent bone raising nor bone fragments in the lesion (except at the extremities).

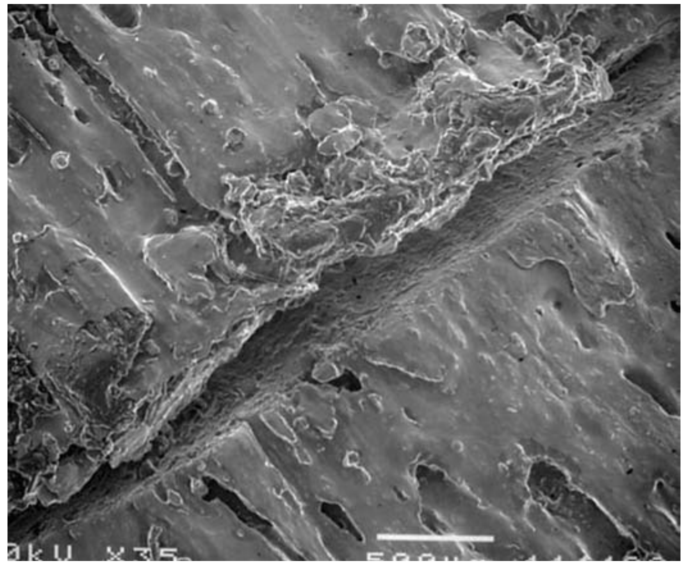

FIG. 4—*Lesion due to the blade of the knife (×35). One of the edges is even, the other is uneven with flakes and a unilateral raising on the adjacent cortical bone.*

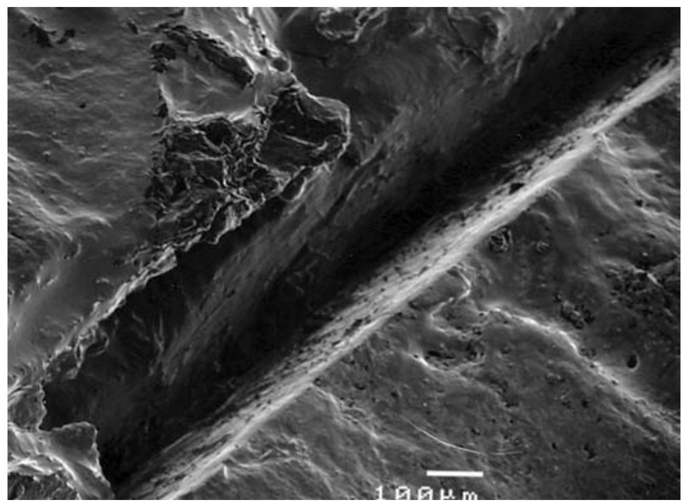

FIG. 5—*Lesion due to the blade of the knife (×100). The walls are even, and there is no lateral pushing back. There are flakes on one edge only.*

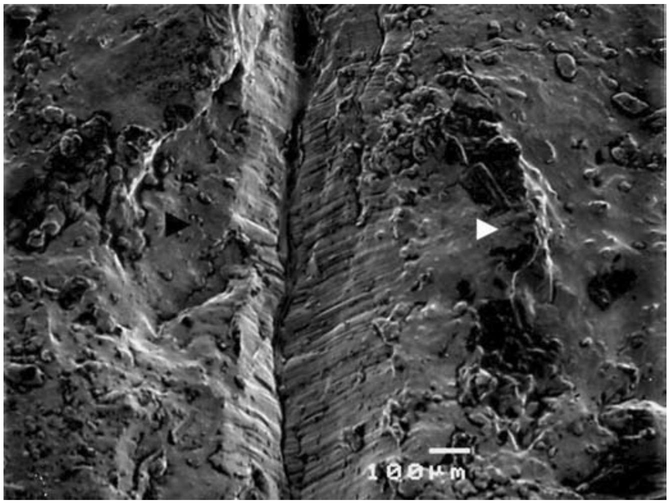

FIG. 6—*Lesions due to the hatchet (×100). The walls are even, the edges uneven. The white arrow shows lateral pushing back and the black arrow shows the flakes on the bone adjacent cortex.*

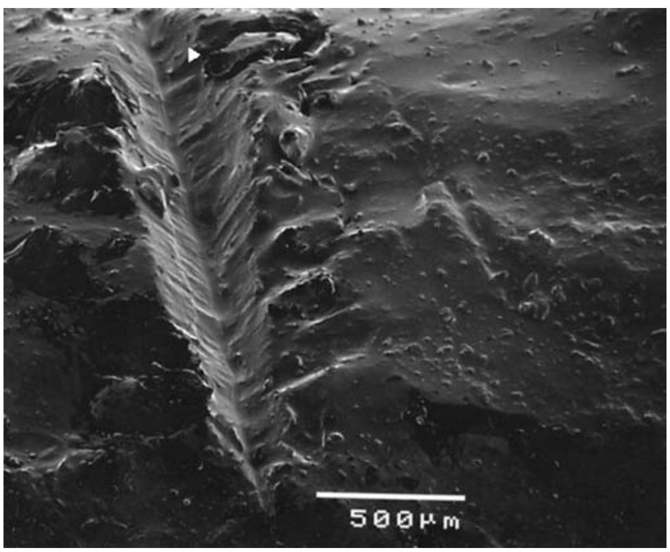

FIG. 7—*Lesions due to the hatchet (×100), with lateral pushing back on side view. The white arrow shows a flake on the right of the lesion.*

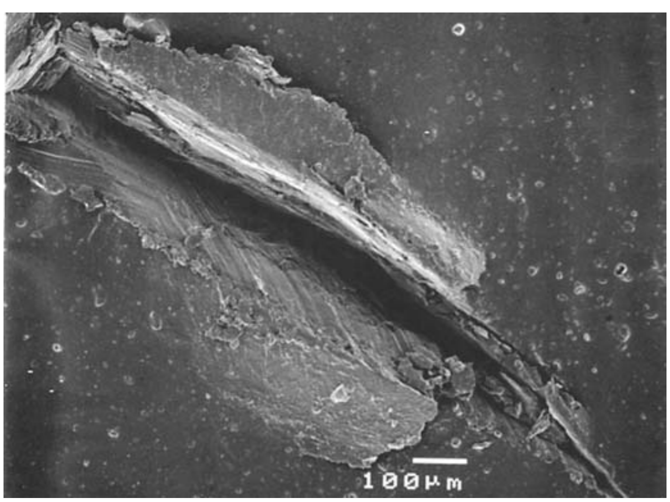

FIG. 8—*Lesion due to the tip of a single blade (×75). One extremity is wide and the other is very thin. These characteristics allow us to determine the orientation of the blade.*

Discussion

In this experimental study on human femur fragments, it is stated that the naked eye is unable to distinguish general class characteristics among the different types of weapons, when the lesions are thin. The macroscopic analysis showed that one of the edges was generally more even in the knife samples than in the hatchet samples. But the lesions were in both cases linear and narrow with either a raising or a small depression near the edges, and it was difficult to accurately macroscopically interpret the edge features. It is well known that the identification of an instrument from a sharp bone lesion is sometimes macroscopically unsound (16). Microscopically, we have shown that specific characteristics could be identified to differentiate between the knife and the hatchet. Bearing in mind in this experiment, that the lesions were rendered with a weak force, which explains why the macroscopic observations were possibly identical.

The main differences between the lesions seen under SEM were the following. With the blade of the knife, the edges were generally more even than with the hatchet ($p < 0.01$ for Edge n°1). The walls and the floor in the two samples were very clean (Fig. 5). This clearly indicates that the mechanism is purely due to a sharp implement. The extremities of the lesion were often thinner in the knife sample and squarer in the hatchet sample because of the thickness of the blade of the instrument ($p < 0.01$). Nevertheless there is an interesting associated phenomenon, which is a unilateral raising of the cortex adjacent to the lesion in the sample stroke by the knife (Fig. 5). This unilateral raising is absent in the hatchet sample. The explanation of this lesion in the knife sample is probably a slight angle between the blade and the surface of the bone: the blade was not fully positioned at a 90-degree angle. Wenham has described in 1989 a similar phenomenon (17): if the blade enters the bone at an angle other than 90°, one of the sides could terminate in fractured bone. We have described in our sample unilateral fractured bone. The unilateral raising and the unilateral fractured bone result from the same mechanism: the pressure of the blade onto the cortex at an angle other than 90°. The bone raising that we have described is a weak zone. A secondary fracture can easily occur in this zone. In ancient material, flakes are often lost showing fractured cortical bone. In our knife sample this raising is associated with flakes and fractured bone, and is commonly unilateral.

With the hatchet the edges are very irregular ($p < 0.01$). Conversely the walls and the floor prove to be even and indicate a sharp mechanism. The bone adjacent lesions showed a significant amount of unilateral or bilateral cortical bone fractures. These fractures are bilateral in 7 samples with the hatchet but only bilateral in 1 sample with the knife. They give a global impression of lateral destruction of the sample, more significant than with the use of a knife. This aspect of destruction is over-estimated by the amount of fragmented bone into the lesion (9 samples), more frequent than with the use of the knife (6 samples) (Table 2). In the hatchet sample, we observed 100% of lateral pushing back (bone laterally compressed) (Fig. 7). This type of lateral pushing back was absent in the knife sample ($p < 0.01$), where only unilateral raising was observed. This result is explained by the quality of the tool.

This significant irregularity of the lesion in the hatchet sample is due to the blunt mechanism. The width and the weight of the instrument are responsible for the lateral pushing back and lateral destruction of the bone. Furthermore the sharp feature of the hatchet blade accounts for the smooth aspect of the walls and floor of the lesion. This leads us to the fact that this chopping weapon acts with a sharp mechanism (the sharp blade), explaining the smooth feature of the lesion, and a blunt mechanism (the width of the blade, the weight of the weapon and the quality of the blade), explaining the ragged edges.

The most important differences between the knife and the hatchet samples appear to be the blunt mechanism associated with the use of the hatchet. In the knife sample, no lateral pushing back was seen ($p < 0.01$).

It was easier to differentiate the lesion caused by the tip of the blade from the other two, because the lesion looked like a puncture. This lesion produced either even or uneven edges, but the walls and the floor were more often clean. The irregularity of the edges is due to the pressure laterally exerted onto the bone, because the depth of penetration of the hard bone with the tip cannot be made only by the sharp part of the tip: there is also a blunt mechanism. Furthermore the lesion is asymmetrical, with a thin part, and a wide part of the lesion at the opposite side. Macroscopically, it was very difficult to determine the orientation of this blade (except in 4 samples). So orientation of the blade was microscopically investigated because of its potential importance in providing details about the manner of death. The SEM analysis showed characteristics that allowed us to determine the orientation of the blade on 14 samples, and to establish that a single blade had been used.

Generally speaking, we can state that the irregularity of the edges of the bone lesion is due to a blunt mechanism that is associated with a sharp mechanism. The SEM hallmarks of this blunt mechanism are represented by the ragged edges, the associated adjacent fractures and the lateral pushing back on the adjacent bone. To facilitate penetration of the weapon, depth pressure has to be exerted laterally on the bone cortex. These features differentiate pure sharp trauma from sharp-blunt trauma. The blunt feature of the lesion is due to the sharp-blunt features of the blade, the width of the blade, the weight of the weapon, the violence of the blow, or the tilt angle. These last four variables are able to put lateral pressure on the bone, entailing a blunt feature to the lesion.

It is now well known that evidence can be grouped into two main types of information: class and individual characteristics. Class characteristics are based upon common features and individual ones are derived from the specific use (18). Sufficient concurrence in class characteristics (general configuration, contour or profile) is important to assess the similarity between the type of tool and the mark (19). One of the ways to do a positive identification consists in matching the tool impression (or negative reproduction of a part of the tool) with the tool itself. But when the marks are extremely thin as in our sample, microscopic examination appears to be necessary, particularly to capture the depth of a wound (2). In homicide investigations we regularly have to study very small marks, especially on fingers, because the shock of the blade can be absorbed by soft tissue. SEM has not frequently been used in the comparison of tool marks (11,18) and the standards of trauma registered in bone have not been established. That is why we have initiated the statement of criteria for the microscopic distinction between knife and hatchet class characteristics.

This experiment is also interesting because the study was done on human bones, whereas the usual publications on the subject, shows studies performed on animal bones (11,18,20). Furthermore, our study concerns contemporary bone remains. Much of published work is documented on ancient skeletal remains or archeological samples (21–24). Moreover this work has confirmed the problem of very narrow lesions whose structures cannot be perceived with the naked eye. It also states that the lesions are reproducible, if the fragment of bone is struck with the same violence (height) and the same tilt, and we removed all soft tissues to enhance the reproducibility of the lesions and the capacity of the bone to record the exact tool characteristics. The most common method of identifying tool marks is by analysing test marks made with a known item in order to establish a standard. But it is dependent upon two dynamic factors: the quality of the tool and the quality of the substrate to be able to receive and record the surface phenomena of the tool. So in this study, we used fully fleshed human femora, in order to enhance the capacity of the bone, to record the specific tool characteristics. One of the strengths of this technique is the clarity with which the visual characteristics present themselves, more especially as the strokes were calibrated. The absence of calibration of the force of the trauma, leads to some difficulty in interpretation of the characteristics of the lesion, because the violence or the tilt of the blow creates different results on the bone (11).

In conclusion, the literature focuses on the general characteristics that are impression-type tool marks produced by a direct pressure contact between tool and bone surface (12). This phenomenon generates evidence of the tool characteristics that are not visible to the naked eye or with light microscopy (4). Our experiment states that the naked eye is not able to distinguish between a slight blow struck by a blade or a hatchet or to orientate a blow. SEM analysis proves to be advantageous in differentiating the general class characteristics of hacking trauma using microscopic criteria, and more generally allows us to understand the mode of action of the sharp mechanism and that of the blunt mechanism in any sharp-blunt trauma.

References

1. Somogyi E, Sótonyi P. On the possibilities of application of scanning electron microscopy in the forensic medicine. Z Rechtsmed 1977;80:205–19. [PubMed]
2. Rawson RB, Starich GH, Rawson RD. Scanning electron microscopic analysis of skin resolution as an aid in identifying trauma in forensic investigations. J Forensic Sci 2000;45(5):1023–7. [PubMed]
3. Katterwe H, Goebel R, Grooss KD. The comparison scanning electron microscope within the field of forensic science. Scan Electron Microsc 1982;2:499–504.
4. Tucker BK, Hutchinson DL, Gilliland MFG, Charles TM, Daniel HJ, Wolfe LD. Microscopic Characteristics of hacking trauma. J Forensic Sci 2001;46(2):234–40. [PubMed]
5. Jakobsen J, Holmen L, Fredebo L, Sejrsen B. Scanning electron microscopy, a useful tool in forensic dental work. J Forensic Odontostomatol 1995;13(2):36–40. [PubMed]
6. Teaford MF. Scanning electron microscope diagnosis of wear patterns versus artefacts on fossil teeth. Scanning Microsc 1988;2(2):1176–5.
7. Maas MC. A scanning electron microscopic study of in vitro flake of mammalian tooth enamel under compressive loads. Arch Oral Biol 1994;39(1):1–11. [PubMed]
8. Quatrehomme G, Bolla M, Muller M, Rocca JP, Grevin G, Bailet P, Ollier A. Experimental single controlled study of burned bones : contribution of scanning electron microscopy. J Forensic Sci 1998;43(2):417–22. [PubMed]
9. Muller M, Bertrand MF, Quatrehomme G, Bolla M, Rocca JP. Macroscopic and microscopic aspects of incinerated teeth. J Forensic Odontostomatol 1998;6,16(1):1–7.
10. Burd DQ, Gilmore AE. Individual and class characteristics of tools. J Forensic Sci 1968;13:390–6. [PubMed]
11. Humphrey JH, Hutchinson LH. Macroscopic characteristics of hacking trauma. J Forensic Sci 2001;46(2):228–33. [PubMed]
12. Davis JE. Striated tool marks. In: Thomas CC, editor. An introduction to tool marks, firearms and the striagraph. Springfield Illinois USA, 1958;26–68.
13. Reichs KJ. Postmortem dismemberment : recovery, analysis and interpretation. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains, Second Edition. Springfield: Charles C. Thomas, 1998;353–88.
14. Symes SA, Berryman HE, Smith OC. Saw marks in bone: introduction and examination of residual kerf contour. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains, Second Edition. Springfield: Charles C. Thomas, 1998;389–409.
15. Rao VJ, Hart RH. Tool mark in cartilage of stabbing victim. J Forensic Sci 1983;28(3):794–9. [PubMed]

16. Maples WR. Trauma analysis by the forensic anthropologist. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C. Thomas,1986;218–28.
17. Wenham SJ. Anatomical interpretation of Anglo-Saxon weapon injuries. In: Hawkes SJ, editor. Weapons and warfare in Anglo-Saxon England. Oxford Univ Committee Archaeol Monogr, 1990;21: 123–39.
18. Houck MM. Skeletal trauma and the individualization of knife marks in bone. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains, Second Edition. Springfield: Charles C. Thomas, 1998;410–24.
19. Burd DQ, RS Greene. Tool mark examination techniques. J Forensic Sci 1957; 2:297–310.
20. Bromage TG, Boyde A. Microscopic criteria for the determination of directionality of cutmarks on bone. Am J Phys Anthropol 1984;65: 359–66. [PubMed]
21. Stirland A. Patterns of trauma in a unique medieval parish cemetery. Int J Osteoarchaeol 1996;6:92–100.
22. Shipman P, Rose J. Early hominid hunting, butchering and carcass-processing behaviors: approaches to the fossil record. J Anthropol Archaeol 1983;2:57–98.
23. Nokes LD, Green M. The use of scanning electron microscopy in the dating of skeletal remains. J Forensic Sci Soc 1987;27(6):413–6. [PubMed]
24. Wakely J, Bruce MF. Interpreting signs of trauma on a human axis vertebra. J Anat 1989;167:265.

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