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**PAPER**

**CRIMINALISTICS**

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# A Method for Studying Knife Tool Marks on Bone

**ABSTRACT:** The characteristics of knife tool marks retained on hard tissues can be used to outline the shape and angle of a knife. The purpose of this study was to describe such marks on bone tissues that had been chopped with knives. A chopping stage with a gravity accelerator and a fixed bone platform was designed to reconstruct the chopping action. A digital microscope was also used to measure the knife angle ($\theta$) and retained V-shape tool mark angle ($\psi$) in a pig skull. The $\kappa$ value (elasticity coefficient; $\theta/\psi$) was derived and recorded after the knife angle ($\theta$) and the accompanied velocity were compared with the proportional impulsive force of the knife and $\psi$ on the bone. The constant impulsive force revealed a correlation between the V-shape tool mark angle ($\psi$) and the elasticity coefficient ($\kappa$). These results describe the tool marks—crucial in the medicolegal investigation—of a knife on hard tissues.

**KEYWORDS:** forensic science, forensic anthropology, biomechanical study, bone trauma, tool marks, digital microscope

According to Edmund Locard's Principle (1910), tool marks play a crucial role in profiling the shape, nature, and characteristics of weapons (1,2). Since 1997, Nichols (3) has stated the firearm and tool mark identification criteria "based at least in part on the scientific method which tests hypotheses by experimenting and making observations" could be used to allow examiners to develop and better articulate their own identification criteria. The tool marks of a knife are especially "eye-catching" on the consecutive matching striations that were initially proposed by Biasotti in 1959 (4). Traditionally, tool mark test exemplars are produced by applying a tool's working surface to a piece of metal so as to replicate the microscopic grooves as well as to demonstrate and compare each different tool's impression. Hence, the imprint of sharp-force instruments on hard tissues has its application in the forensic sciences. Except for the striations of knife marks, little research has been conducted, particularly on the quantitative analyses of cut marks on bones. Tucker et al. (5) related a class of hacking weapons, including machetes, axes, and cleavers, to trauma inflicted on bones by way of striation analysis. Knife marks on hard tissues retain their characteristics—including the knife shape, striations, and engraved patterns—that provide the details of a knife, including the shape and angle. The consecutive matching striations of a knife are easily misinterpreted as biological striations as all mammalian bones are fine lamellar bones filled with numerous secondary osteones (6). Cut marks of a knife wound, as exemplified on bone, are characterized by narrow blade dimensions—a V-shaped cross-section with striations perpendicular to the kerf. The groove made with a cutting tool is suggestive of the blade dimensions of the offending weapon (7). Sharp-force injuries inflicted by an axe or saw tend to demonstrate more damage and produce patterns that are morphologically distinct from those by knives (7). In 2006, Saville et al. (8) demonstrated unique saw marks on bones by describing at least three types of striations on saw marks and false-start kerfs produced by a raker saw and mapped the three dimensions of the saw including the width and furrows of the saw. Alunni-Perret et al. (9) compared irregular edges of bone lesions owing to a blunt mechanism with sharp–blunt trauma such as by an axe using four variables: the sharp–blunt features of the blade, width of the blade, weight of the weapon, and violence of the blow or the tilt angle. When the lateral pressure is imposed on bones, these four variables determine the blunt feature of the lesions (9,10). The purpose of this study is to identify the retained V-shape tool mark angle on pig skulls, which were chopped with a unique flat-grind knife. Mapping three dimensions of tool marks, including the knife angle associated with V-kerf morphology, can help trace the shape and type of the chopping knife.

## Materials and Methods

### *Digital Microscope*

Knives can be classified into two types: (i) asymmetrical and chisel-grind knives that have a right angle on one side of the blade and (ii) symmetrical and flat-grind knives with an isosceles triangle-shaped blade (http://en.wikipedia.org/wiki/Grind). Two flat-grind knives with different knife angles ($\theta$ measured at 1.0 mm distance from the tip of the edge) were selected for this study.

The instrument used to measure knife angles was a three-dimensional (3D) digital microscope, model HIROX KH-7700 (HIROX Co. Ltd., Tokyo, Japan) (Fig. 1). It is a reflective and perspective dual-use digital optical microscope with a wide range of camera specifications. Its magnification ranges from 50 times to 1000 times, applicable for a variety of purposes. With a computer

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image–measuring program, it is able to measure the length, radius, angle, and area of the material in question. It is also capable of taking images from different focal planes (at different heights) and digitally merging them into a single 3D picture. Such a picture will then be used to measure the knife angle ($\theta$) and V-shape tool mark angle ($\psi$) on a pig skull during a chopping simulation experiment (Fig. 2*a*, Fig. 2*b*).

The calibration and accuracy of the 3D digital microscope were checked by grade 2 (or grade A) gauge blocks (thickness of 1.0 and 1.5 mm; Kaizer, USA) and were compared with a thickness gauge. Both gauge blocks were measured by two instruments, 20 times each. With the same method, the angles of knife 1 and knife 2 were measured.

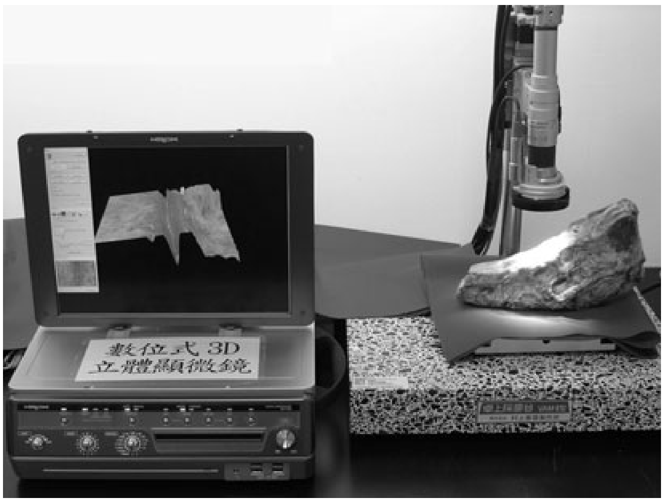


FIG. 1—*Digital microscope: HIROX KH-7700 with morphometric device.*

*Establishment of the Experimental Chopping Stage*

Experimental instruments included a knife holder, a stage with adjustable momentum for the knife, and a fixed bone platform (Fig. 3). The knife holder dropped to produce impulsive force on a bone, simulating hand chopping. Humans produce angular momentum by switching their arms, and when the knife touches a bone, angular momentum is converted to linear momentum, generating impulsive force on the bone. On the stage, the height between the knife and the fixed bone platform was adjusted with sliding bearings, pulley, and cable wire. A pig skull was held on a steel platform by fixing it with unsaturated polyester resin. This fixed bone platform was supported by compact plain bearings; a bearing shaft on rolling balanced gears was also used to make sure that pig skulls were firmly fixed and horizontal to the ground.

*Reconstruction of the Chopping and Measurement of the V-Shape Tool Mark Angle on the Pig Skull*

Clearly defined and constructed, the experimental settings precisely simulated to ensure reproducibility. The impulsive energy of the knife was calibrated with the knife's gravity force. The impulsive energy used to inflict trauma was proportional to the heights of the knife at 44.1, 78.4, and 122.5 cm after a trial at 19.6 cm. The mapping of the V-shape knife imprint, including cross-section of the chopped bone groove and V-shape tool mark angle ($\psi$), was established and probed by the 3D digital microscope (HIROX KH-7700).

*Data Analysis and Comparison*

The $\kappa$ value ($\theta/\psi$) was defined as the elasticity coefficient and was obtained after the knife angle ($\theta$) and retained V-shape tool mark angle ($\psi$) on the chopped bone tissue were compared. The impulsive energy of the knife was calculated by multiplying

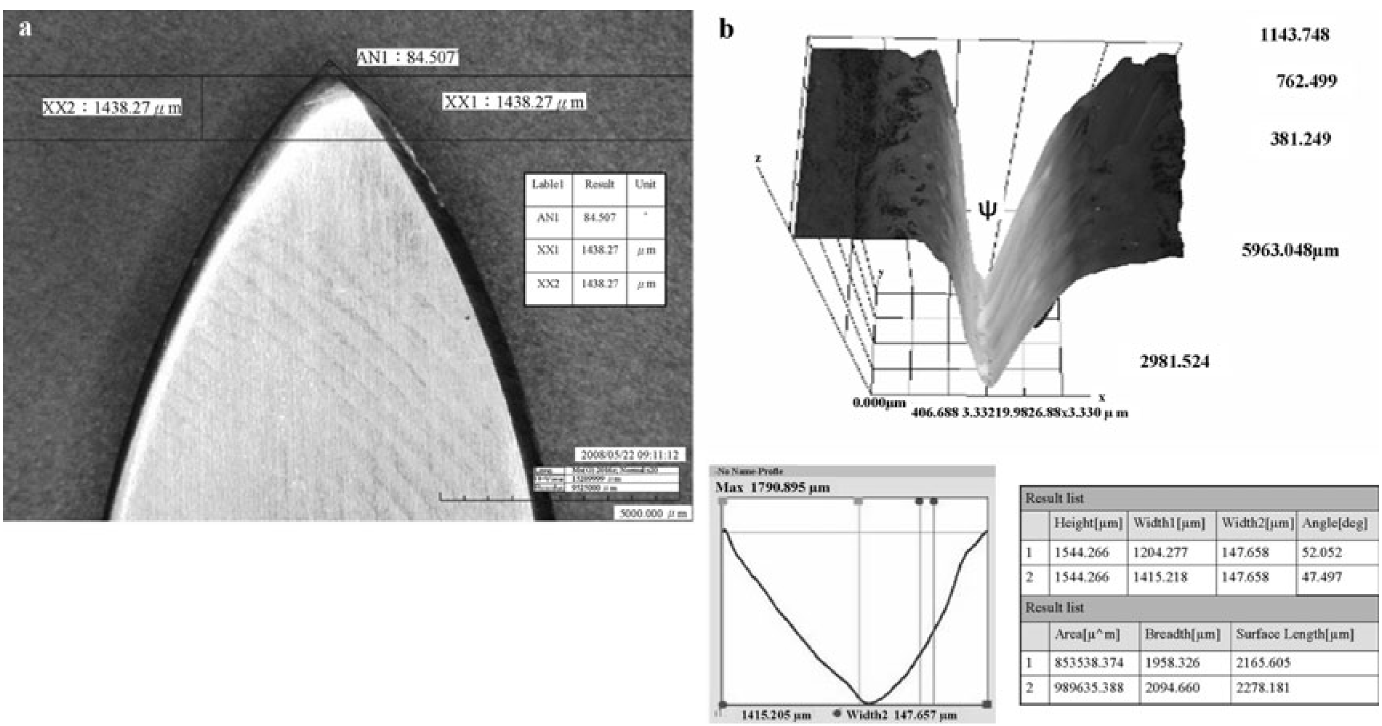


FIG. 2—*Mapping the knife blade (a), using digital microscope mapping the V-shape tool mark (b).*

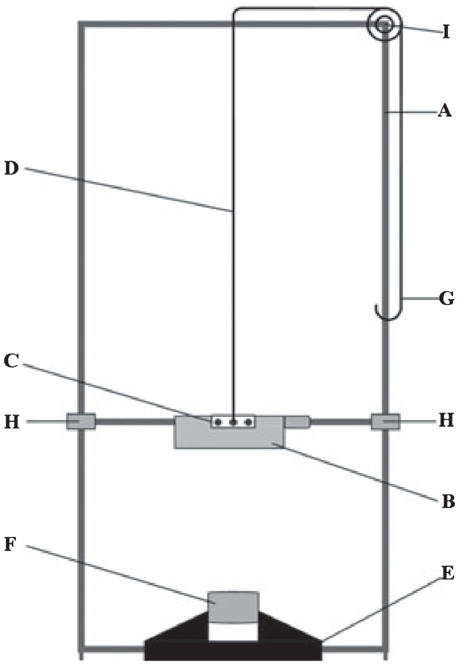


FIG. 3—*Chopping stage: (A) frame, (B) chopping knife, (C) screw fixed, (D) cable wire, (E) fixture, (F) pig bones, (G) ouch, (H) slide bearing, and (I) pulley.*

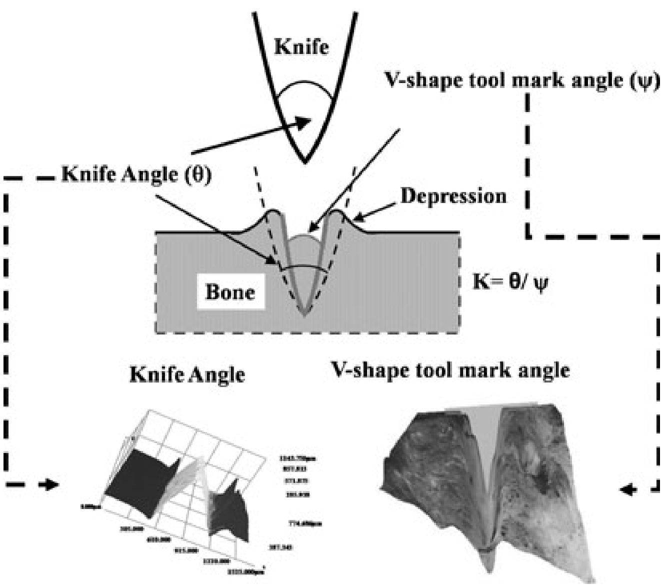


FIG. 4—*Measuring the knife blade and knife mark on bone using digital microscope.*

the knife's gravity force and the designated height in each experiment. Measurement data of knife angles and tool mark angles on bones were statistically analyzed, and the results were found correlated with the bone elasticity coefficients and *vice versa* (Fig. 4).

## Results

The experimental data of gauge blocks measured with a thickness gauge and HIROX KH-7700 are shown in Table 1. Values were observed by HIROX KH-7700 at 1.50 ± 0.00 mm (mean ± SD) and 1.00 ± 0.00 mm, while those of the thickness gauge were 1.51 ± 0.02 and 1.01 ± 0.02 mm. The angles of knife 1 and knife 2 were 22.10° ± 0.71° and 35.14° ± 1.62°, respectively. The experimental data of different knives and heights are shown in Table 2. The relation curve of the V-shape tool mark angles and the impulsive forces is shown in Fig. 5. The relation curve of bone elasticity coefficients and the impulsive forces is shown in Fig. 6. The relation curve of depth of knife tool marks and the impulsive energy is shown in Fig. 7. The experimental results demonstrate a positive, linear correlation between the elasticity coefficients and the impulsive forces.

TABLE 1—*Experimental data of gauge block measurements.*

| Measurement | Thickness Gauge | HIROX KH-7700 |
|---|---|---|
| Gauge block (1.0 mm) | 1.01 ± 0.02 | 1.00 ± 0.00 |
| Gauge block (1.5 mm) | 1.51 ± 0.02 | 1.50 ± 0.00 |

## Discussion

### *Calibration by Gauge Block*

The calibration checking test was performed on the 3D microscope, HIROX KH-7700, with two gauge blocks (thickness of 1.0 and 1.5 mm) and a thickness gauge. The statistic results of gauge block measurements are shown in Table 1, indicating good and acceptable reproducibility and precision of the digital optical measurement method.

### *Elasticity Coefficient and V-Shape Tool Mark Angle*

Under the conditions of constant knife weight (gravity accelerator) at a height between 19.6 and 122.5 cm, the V-shape tool mark angle ($\psi$) and elasticity coefficient ($\kappa$) of chopped bone tissues were found to be between 31.28 and 10.16° and 1.12–2.18, respectively. These results indicate a linear correlation between the V-shape tool mark angle and the impulsive force, as well as a positive, linear correlation between the elasticity coefficients and the impulsive forces. The reason may be that when a knife fell from a greater height, its velocity increased, thus leading to a greater impulsive force on the bone tissues struck by the knife. Because living bone has elasticity, more intense external force exerted on a bone increases the rebound off the bone. Greater rebound off a bone was generated under a larger percussive impact. After experimenting with flat-grind knife on pig skulls, it was discovered that a higher external force resulted in deeper bone V-kerf, accompanied by higher bone elastic resistance as well as a higher elasticity coefficient. Based on these data, the patterns of a knife chop were profiled—including the weight, type, and angle of the knife as well as the impulsive force.

### *Chopping Depth*

A linear relationship between the impulsive energy and chopping depth is shown in Table 2 and Fig. 7. The result is because of the decrease in impulsive energy caused by the resistance. According to the rule of conservation of energy, the impulsive energy could be taken as equaling the average resistance times the depth. In other words, the impulsive energy and chopping depth emerge in a direct ratio. This offers a simple way to calculate the average resistance from the reciprocal of the curve's slope in a depth-impulsive energy graph. Figure 8 shows that a larger knife angle will create a larger component force. To balance the component forces, the

TABLE 2—*Relation among knife angle (θ), impulsive force, V-shape tool mark angle (ψ), and elasticity coefficient (κ) of the pig bone chopping.*

| Knife Number | Height (m) | Velocity (m/s) | Impulsive Force (kg-m/s) | Impulsive Energy (kg-m$^2$/s$^2$) | V-Shape Tool Mark Angle (ψ) | κ (θ/ψ) | Depth (mm) |
|---|---|---|---|---|---|---|---|
| Knife 1 Flat-grind | 0.196 | 1.96 | 9.8 | 9.60 | 18.29 | 1.21 | 1.03 |
| blade (θ = 22.10°) | 0.441 | 2.94 | 14.7 | 21.61 | 15.16 | 1.46 | 3.01 |
| | 0.784 | 3.92 | 19.6 | 38.42 | 12.12 | 1.82 | 5.31 |
| | 1.225 | 4.90 | 24.5 | 60.03 | 10.16 | 2.18 | 11.69 |
| Knife 2 Flat-grind | 0.196 | 1.96 | 9.8 | 9.60 | 31.28 | 1.12 | 0.67 |
| blade (θ = 35.14°) | 0.441 | 2.94 | 14.7 | 21.61 | 29.10 | 1.21 | 1.28 |
| | 0.784 | 3.92 | 19.6 | 38.42 | 22.82 | 1.54 | 2.37 |
| | 1.225 | 4.90 | 24.5 | 60.03 | 18.14 | 1.94 | 5.03 |

Total weight = 5 kg.

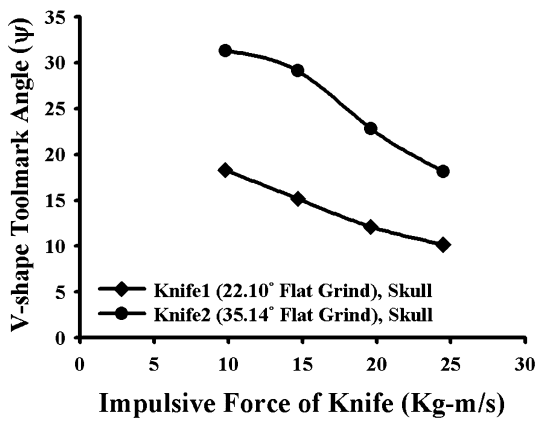


FIG. 5—*Relation between V-shape tool mark angle and impulsive force.*

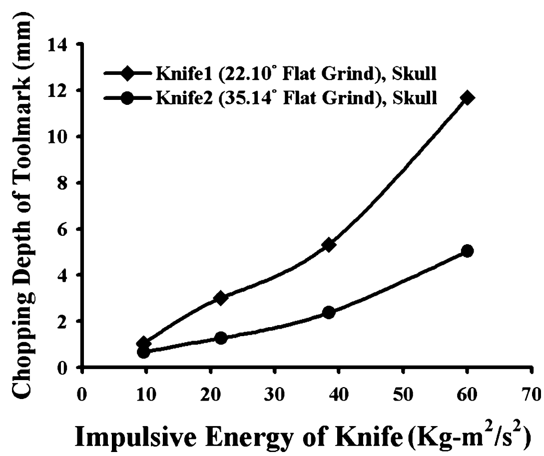


FIG. 7—*Relation between depth and impulsive energy.*

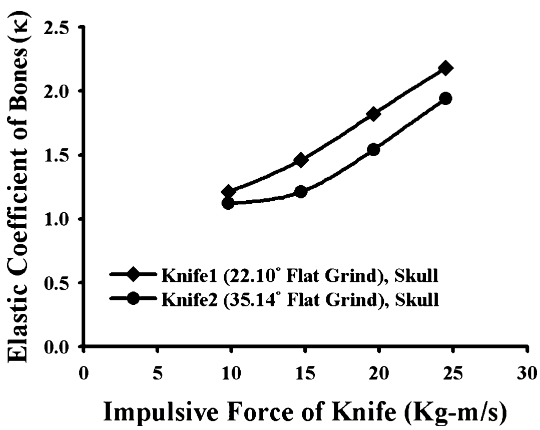


FIG. 6—*Relation between elastic coefficient and impulsive force.*

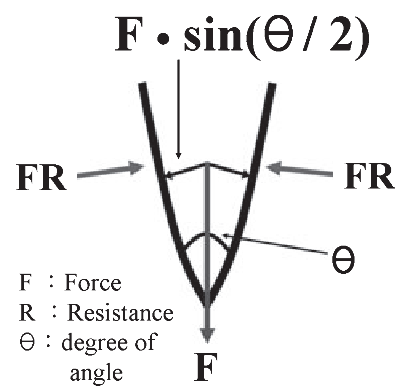


FIG. 8—*Diagram of flat-grind blade tip.*

knife would encounter a larger resistance. By calculating the reciprocal of the slope, similar results are also shown in Fig. 7.

## Conclusions

As living bones have elasticity, knife tool marks on bones often fail to reflect the knife angle in an attempted practical interpretation. By experimenting on knife tool marks to find the elasticity coefficients, the impulsive force, etc., one can characterize the subject knife and determine features such as the grind shape and other physical characteristics of the blade to finalize the mapping of the knife. Our results imply the flat-grind blade can produce a unique shape of chops on bones, which is different from the shape produced by a chisel-grind blade. These results contribute to the criminal forensic investigation.

This research initially used the knife tool mark simulation platform, on which the impulsive force was adjusted to simulate the knife tool marks. Furthermore, both the knife angle and knife tool marks were measured accurately and easily using a digital 3D optical microscope. By calculating the elasticity coefficient of chopped bones and checking the impulsive force, we could simulate where and how the force might have been exerted. In addition to bone striations, the retained knife marks on hard tissues also play a crucial role in profiling the characteristics of a knife in a medicolegal investigation.

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