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Quantitative Analysis of Sharp-Force Trauma: An Application of Scanning Electron Microscopy in Forensic Anthropology*

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ABSTRACT: Scanning electron microscopy (SEM) has occasionally been used by anthropologists and forensic scientists to look at morphological characteristics that certain implements leave on bone. However, few studies have addressed techniques or protocols for assessing quantitative differences between tool marks on bone made by different bladed implements. In this study, the statistical variation in cut mark width was examined between control and test samples on bone using a scalpel blade, paring knife, and kitchen utility knife. Statistically significant differences ($p < .0005$) were found between cut marks made by the same knife under control and test conditions for all three knife types used in the study. When the control sample and test samples were examined individually for differences in mean variation between knife types, significant differences were also found ($p < .0005$). While significant differences in cut mark width were found, caution should be used in trying to classify individual cut marks as being inflicted by a particular implement, due to the overlap in cut mark width that exists between different knife types. When combined, both quantitative and qualitative analyses of cut marks should prove to be more useful in trying to identify a suspect weapon. Furthermore, the application of SEM can be particularly useful for assessing many of these features.

KEYWORDS: forensic science, forensic anthropology, sharp-force trauma, tool mark analysis, cut mark, knife, scanning electron microscopy

In recent years, the role of the forensic anthropologists has expanded into new areas. While forensic anthropologists typically provide a biological profile of unidentified remains, many researchers are also becoming more involved in the analysis of sharp-force trauma to the skeleton (1–4). Tool mark analysis has been a prominent area in the forensic sciences, although little research has been directed specifically to quantitative analyses of cut marks on bone. While quantitative approaches have been utilized in the estimation of entrance wound diameter in an attempt to determine bullet caliber (5), most studies of tool marks on bone have addressed only qualitative morphological features.

The Association of Firearm and Tool Mark Examiners define impressed tool marks as, "Marks produced when a tool, or object, is placed against another object and enough force is applied to the tool, or object, so that it leaves an impression. The class characteristics (shape) can indicate the type of tool used to produce the mark (6)." Burd and Kirk (7) report that no two implements will produce identical tool marks, nor will the same tool produce an identical tool mark. Morphological features caused by sharp implements, such as identifiable striations, often can be used to positively match a particular tool mark to a suspect weapon (3,8–12).

Sharp-force trauma can be defined as chopping, stabbing, or slashing wounds inflicted by a sharp object, such as a knife or saw (10). Knife wound cut marks, as exemplified on bone, are characterized by narrow blade dimensions, a V-shaped cross section, striations which are perpendicular to the kerf floor, and minimal wastage (3). The width of a kerf, the groove made by a cutting tool, has been suggested to reflect the blade dimensions of the offending weapon (3). Sharp-force injuries inflicted by an axe, or saw, in comparison tend to exhibit more damage, and further leave patterns that are morphologically distinct from knives (3).

The use of scanning electron microscopy in the qualitative analysis of cut marks has been shown to be a useful tool for determining blade stroke directionality, the differentiation of perimortem and postmortem sharp trauma, and in the positive identification of knife striation marks with a suspect weapon (3,8,13). This preliminary study demonstrates the application of a quantitative technique used to examine cut mark width between control and test samples created by three different bladed implements. Although sharp-force injuries can be inflicted by wide range of sharp implements, the present study is limited to the analysis of cut marks inflicted by knives.

Methods

A single macerated humerus taken by the mid-South Tissue Bank, Tennessee was used for the purposes of this experiment. The knives used in this study (Fig. 1) were newly purchased, nonserrated stainless steel blades and included: a scalpel blade (Hamilton Bell, Inc.™); paring knife (Tramontina™); and kitchen utility knife (Tramontina™). Digital caliper readings indicate a blade width of .38 mm for the scalpel blade, .95 mm for the paring knife, and 1.14 mm for the utility knife.

The null hypothesis of no difference was used to test: (1) whether cut mark widths made by different knife types were significantly different; and (2) whether knife cuts made by the same knife under control and test conditions were significantly different. Figure 2 illustrates the basic morphological features of a scalpel blade cut mark as viewed under SEM.

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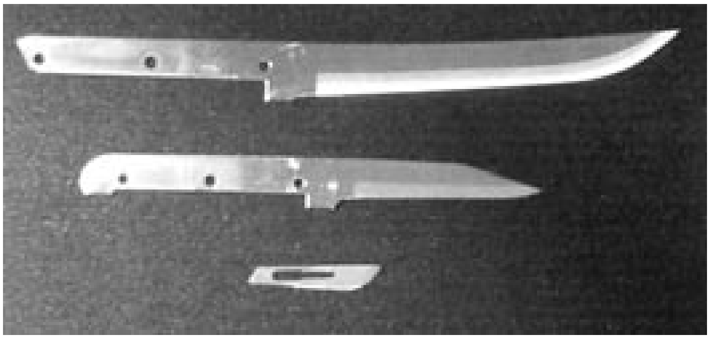

FIG. 1—*Photograph illustrating sample knife blades with handles removed, beginning with the utility knife, paring knife, scalpel blade, and knife holder (top to bottom).*

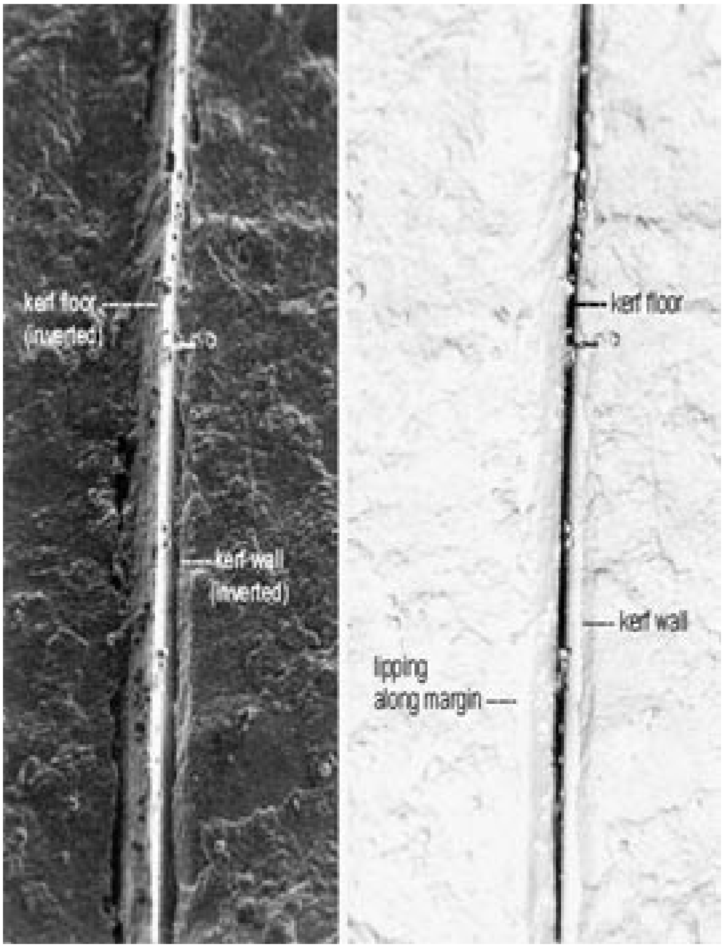

FIG. 2—*SEM image of a scalpel blade cut on bone. Image on the left is a negative impression, showing the inverted kerf floor superiorly. Image on the right represents the same cut mark converted to a positive image.*

Knife blades were carefully removed from their handles and mounted to an increment machine (Acu-rite .001 mm, Absolute Zero II™) for the control samples. This machine is designed to count increments of various types (e.g., fingerprint ridges and cementum layers in teeth), but is uniquely suited to the purposes of this experiment because it ensures replicability with regard to the direction, angle, and force of blade stroke. The increment machine allows for precise control over the movement of both the blade and bone sample, which were positioned along the *x* and *y*-axes of the instrument. Blades were fixed along the *x*-coordinate arm of the machine to prevent movement. Similarly, the bone sample was fixed along the *y*-coordinate arm in the path of the blade on the *x*-axis. Cut marks were created using a rotating dial on the increment machine, which advanced the blade over the surface of the bone. A contractor's level was also used to ensure that the bone surface and blade remained level, which maintained, for each cut mark, approximately the same distance between the lowest point of the blade surface and the increment machine floor.

Sixty cut marks were created for both the control and test samples, 20 for each knife type. Casts made for 89 of these cut marks were suitable for analysis, with individual sample sizes varying between 10 and 18. The control samples consisted of 10 scalpel blade cut marks, 16 paring knife cut marks, and 14 kitchen utility knife cut marks. The test samples consisted of 18 scalpel blade cut marks, 17 paring knife cut marks, and 14 kitchen utility knife cut marks created with the same knives used in the control samples. Cut marks were created manually, oriented to the axis of the bone at varying levels of force and angle.

The cut marks for each blade type were cast using Mikrosil forensic casting material and were trimmed to fit a 15-mm SEM mounting stub. The samples were then sputter-coated with gold for 1.5 min prior to viewing under the SEM. All micrographs were taken at 50× magnification and stored on a computer disk. Each image was examined using UTHSCSA Image Tools 1.27™, a computer program designed for the quantitative analysis of images. The maximum cut mark width, calibrated to a micrometer bar located on each image, was measured by drawing a computer-generated line connecting both sides of the kerf (cut mark) wall (Fig. 3). Five separate locations on each cut mark were measured to ensure that the maximum width was recorded as agreed upon by two observers. The data was entered into the Statistical Package for the Social Sciences (SPSS 9.01 Student Version™) for statistical analysis. Independent sample *t*-tests were computed to determine whether significant differences existed between the control and test samples for each blade type, and a one-way analysis of variance (ANOVA) was used to compare the within-means variance to the between-means variance in both the control and test samples.

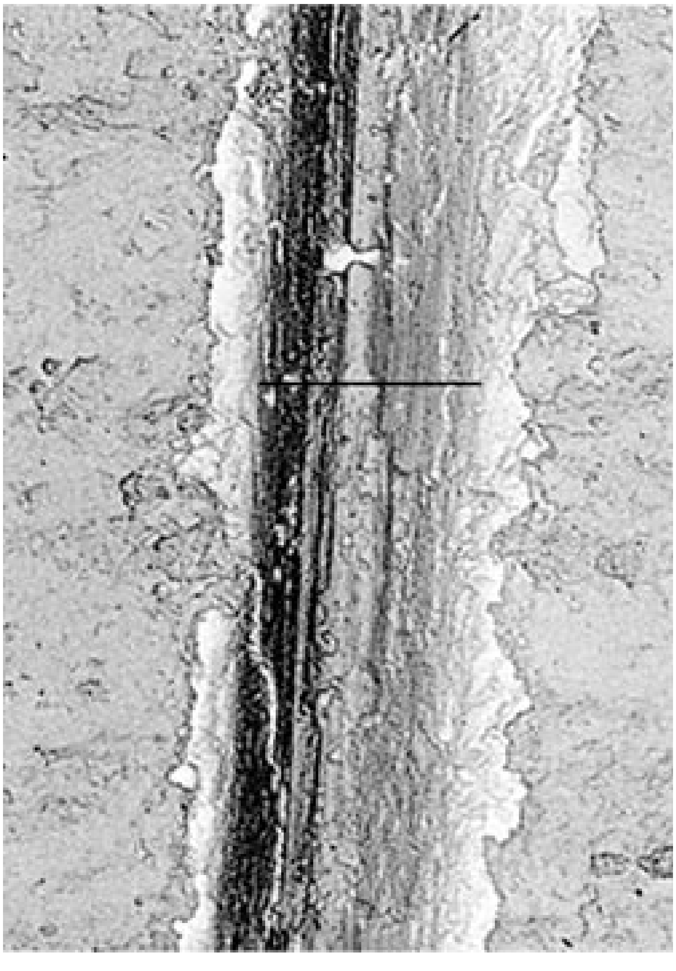

FIG. 3—*SEM image showing calibrated micrometer bar across the width of the kerf edge. The largest width of five was used as the maximum width as agreed upon by two observers.*

Results

Quantitative Analysis

Cut marks for each knife type are illustrated in Fig. 4. The results for each independent sample *t*-test demonstrate statistically significant differences ($p < .0005$) in mean cut mark width between the control and test samples for all three knife types. The results of ANOVA also demonstrate statistically significant differences ($p < .0005$) between each blade type within the control and test samples. Cut mark width in the control samples ranged from 40.7 to 65.7 μm for the scalpel blade, 72.1 to 173.3 μm for the paring knife, and 128.1 to 334 μm for the utility knife. For the test samples, scalpel cut width ranged from 36.3 to 181.2 μm, 105.0 to 277.2 μm for the paring knife, and 239.7 to 504.5 μm for the utility knife. The mean widths for the control samples were 51.6, 117, and 211 μm for the scalpel, paring, and utility blade cuts respectively, while for the test samples, the mean widths were 102.4, 207.5, and 326 μm (Table 1).

Discussion

The results of the independent *t*-tests show that when blade stroke force and angle were controlled, cut mark width was significantly less than in the test samples (Table 1). The wider kerf widths exhibited within the test sample cut marks can be explained by the variability in force and angle applied in creating each cut. While the test sample cuts were much wider than in the control sample for each blade type, the utility knife created the widest kerf, followed by the paring knife and scalpel blade. The ANOVA results demonstrate that there is more variation in mean kerf width between cut marks made by different implements than there are within each individual knife type category for both the control and test samples. Simply, the mean widths created by each knife were significantly different ($p < .0005$) from one another in the control and test samples.

Although the differences for each blade type are highly significant, several potential biases must be addressed. First, significant differences between mean kerf width in the control and test samples for each implement show that the effects of blade stroke force and angle dramatically influence the width of the cut, resulting in widened kerf walls with associated splaying of bone. Another factor, the degree of overlap that exists between individual cut mark widths created by the different implements, may result in misclassification of knife type (Figs. 5 and 6). Other potential concerns not addressed in this study include the effects of differences in bone density, as well as more methodological concerns such as observer error in judging the actual width of the kerf from SEM images.

Conclusions

Although a statistically significant relationship exists between blade type and cut mark width, overlap between cut mark widths from different knife types in both the control and test samples

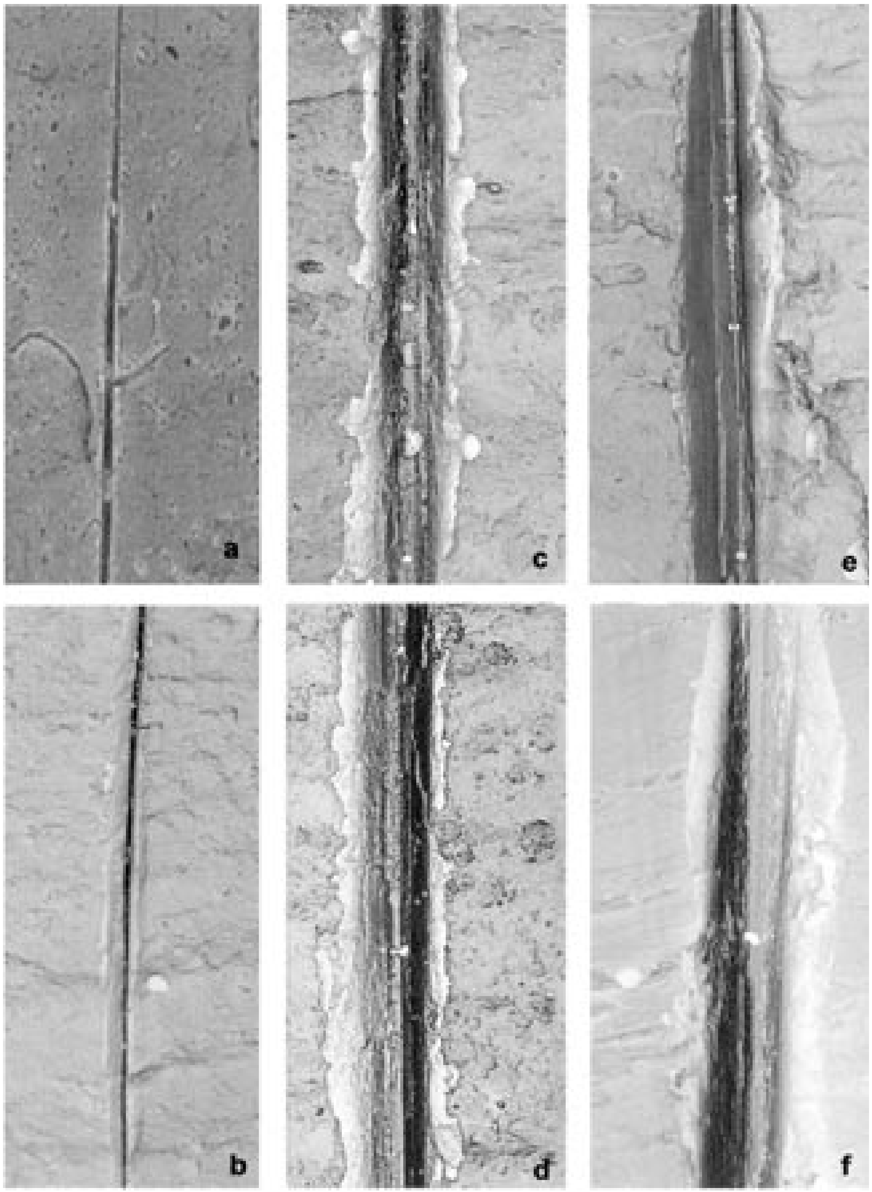

FIG. 4—*SEM images of cut marks made by each knife type in the control and test sample.* (a) *= control sample scalpel blade;* (b) *test sample scalpel blade;* (c) *control sample paring knife;* (d) *test sample paring knife;* (e) *control sample utility knife;* (f) *test sample utility knife.*

demonstrates that caution should be exercised when trying to classify a cut mark as belonging to a particular implement. More useful are the qualitative and quantitative consistencies that exist between a particular knife and cut mark, which, taken together, will provide information that is more reliable for aiding in the identification of a suspect weapon.

The differentiation of scalpel cuts from other knife types may be possible by their relatively small blade widths and consistent and uniform pattern they exhibit on bone (Figs. 2 and 4). In instances where remains are macerated using scalpel blades, accidental cut marks should be able to be differentiated from perimortem trauma with a reasonable degree of accuracy. The results of this preliminary study show that the application of SEM should provide further new avenues of research for both the qualitative and quantitative analysis of tool marks on bone.

TABLE 1—*Cut mark width, range, and standard deviation for each knife type (recorded in micrometers).*

Knife Type	Mean Cut Mark Width	Range	S.D.
Control Sample			
Scalpel (n = 10)	51.6	40.7–65.7	8.6
Paring (n = 16)	117.0	72.1–173.3	26.7
Utility (n = 14)	211.0	128.1–334.0	52.1
Test Sample			
Scalpel (n = 18)	102.4	36.3–181.2	39.7
Paring (n = 17)	207.5	105.0–277.2	35.9
Utility (n = 14)	326.0	239.7–504.5	93.3

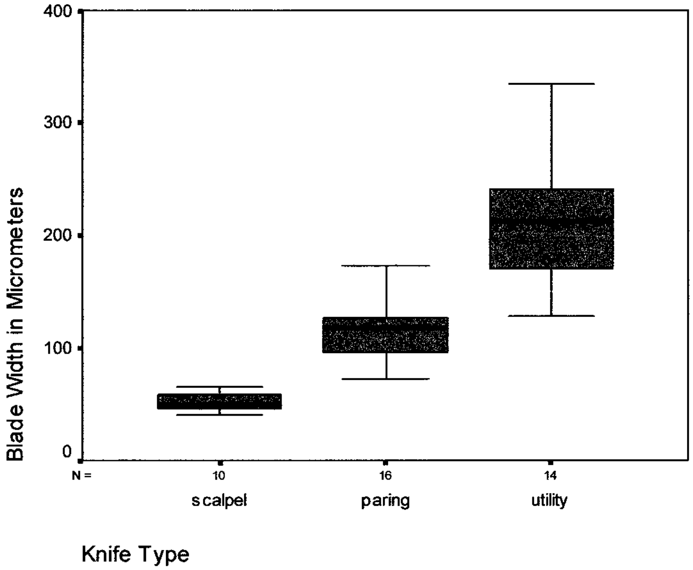

FIG. 5—*Box and whisker plot of cut mark variation in the control sample.*

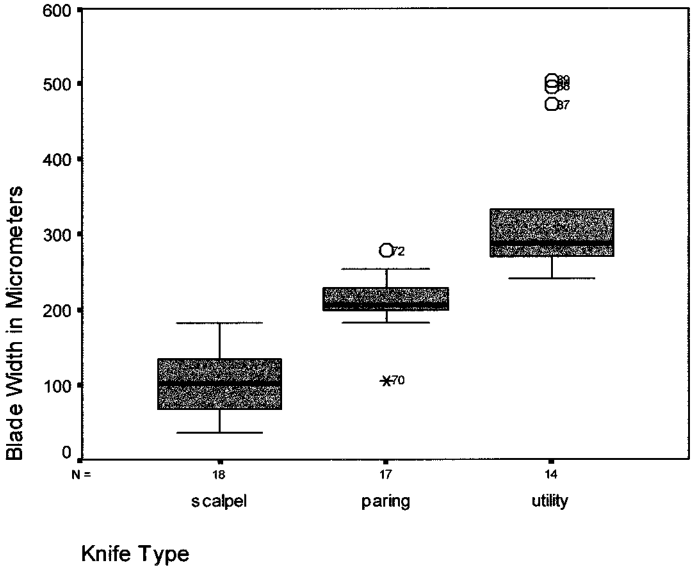

FIG. 6—*Box and whisker plot of cut mark variation in the test sample.*

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