J Forensic Sci, Nov. 2003, Vol. 48, No. 6
Paper ID JFS2002220_486
Available online at: www.astm.org

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Forensic Microradiology: Micro-Computed Tomography (Micro-CT) and Analysis of Patterned Injuries Inside of Bone

ABSTRACT: When a knife is stabbed in bone, it leaves an impression in the bone. The characteristics (shape, size etc.) may indicate the type of tool used to produce the patterned injury in bone. Until now it has been impossible in forensic sciences to document such damage precisely and non-destructively. Micro-computed tomography (Micro-CT) offers an opportunity to analyze patterned injuries of tool marks made in bone. Using high-resolution Micro-CT and computer software, detailed analysis of three-dimensional (3D) architecture has recently become feasible and allows microstructural 3D bone information to be collected. With adequate viewing software, data from 2D slice of an arbitrary plane can be extracted from 3D data sets. Using such software as a "digital virtual knife," the examiner can interactively section and analyze the 3D sample. Analysis of the bone injury revealed that Micro-CT provides an opportunity to correlate a bone injury to an injury-causing instrument. Even broken knife tips can be graphically and non-destructively assigned to a suspect weapon.

KEYWORDS: forensic science, radiology, micro-computed tomography, patterned injury, tool mark analysis, digital virtual knife

Toolmark analysis is a prominent but a difficult area in forensic sciences and has recently been a subject of criticism (1–6). Unfortunately, knife wound analysis has also been ignored or inadequately documented, e.g., historically utilizing meaningless categories such as "sharp" or "single-edged," and other misleading or errant descriptive terminology (5). When a knife penetrates bone, this sharp tool leaves an impression in the bone. The characteristics (shape, size etc.) indicate the type of tool used to produce the patterned injury in bone. Until now it has been impossible in forensic sciences to document such damage precisely and non-destructively. Recently technologies have been developed to analyze toolmarks on bone but there is currently no adequate method for quantitative analysis of stabbing knife wounds in bone (1,4–6).

Micro-computed tomography (Micro-CT) was introduced in the mid 90's as a scaled-down, high-resolution imaging method in the medical field. Micro-CT was then predominately used for osteoporosis research (7–11). Most recently the Micro-CT technique has been introduced for follow-up studies of living, transgenic, and knockout mice in cancer research (12,13). In this research domain, Micro-CT methods allows the continuous monitoring of changes in vivo, for example, tumor development. As a result, the transgenic mice need not be sacrificed in order to measure, for example, the size of an artificially induced tumor. In the forensic field, Micro-CT offers a worthwhile opportunity to analyze patterned injuries of tool marks inside a bone. Using high-resolution Micro-CT and computer software with detailed analysis of three-dimensional (3D) architecture, it has recently become feasible to obtain microstructural 3D bone information.

The purpose of this study is to address whether 3D methods of Micro-CT have the potential to examine stabbing wounds in bone with high resolution in a non-invasive manner.

A homicide case with sharp force injuries to skin, soft tissue and skeletal tissue (pelvis) served as a test case for this study. In this case, the suspect knives were cleaned and there was no DNA evidence to link the injury to one knife. Examination of the injuries to the skin provided no clue to the type of instrument used. The question asked was: Is there an injury pattern in the bone that would narrow down the range of potential knives capable of providing the observed skeletal injury? A more accurate description of a knife could possibly limit the range of suspects in this case.

Material and Methods

In order to simulate more accurately this specific homicide case for this study, porcine pelvic bones were stabbed with various knives (Figs. 1–4). The removal of the knives from the bones were carried out with and without a rotational movement component (rocking the knife back and forward or twisting the blade on its longitudinal axis; see Figs. 1,2). The bone was carefully macerated by an enzymatic process using Enzyrem (Fa. Nusser, Zurich, Switzerland) (Fig. 4). The bone specimens were examined with a Micro-CT system developed and built at the Institute of Medical Physics Erlangen, Germany (Fig. 5). This Micro-CT scanner can image a 3D volume with an isotropic resolution, i.e., a similar resolution in all three spatial axes (e.g., x,y,z) (7,8). Our

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Received 29 June 2002, and in revised from 13 April and 17 June 2003; accepted 17 June 2003; published XXXX.

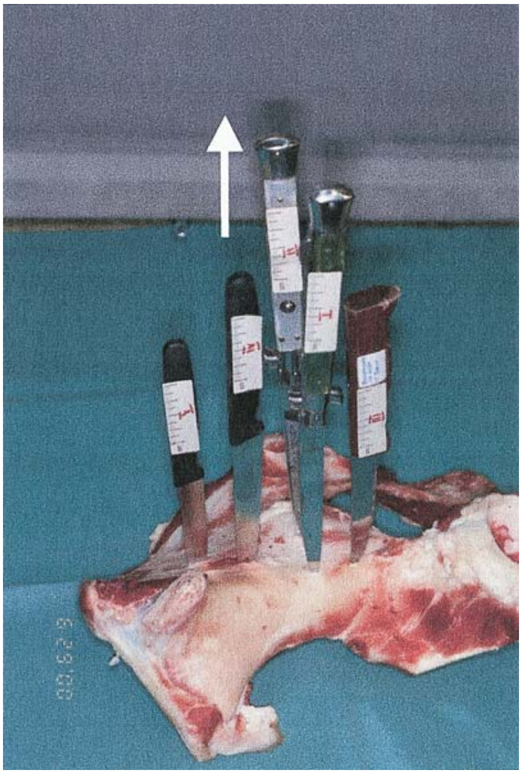

FIG. 1—*Experimental set-up: straight stabs to the porcine bone.*

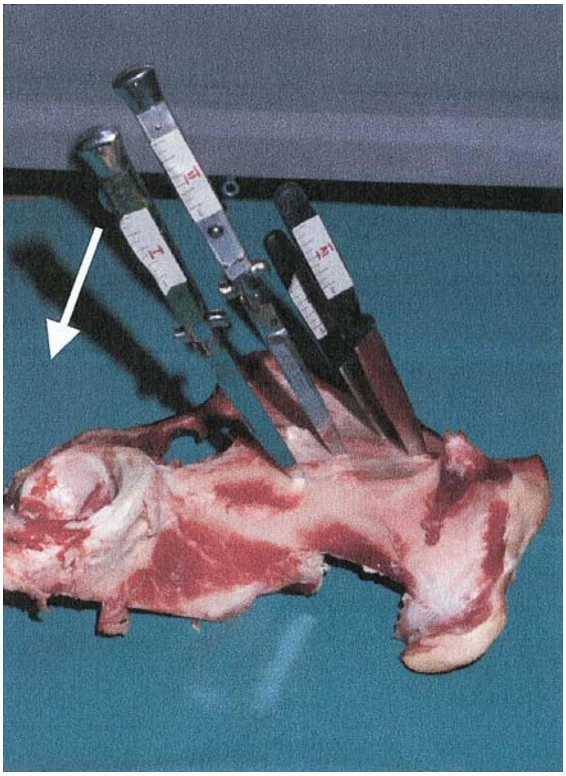

FIG. 2—*Same set-up as in Fig. 1 but with rotational component.*

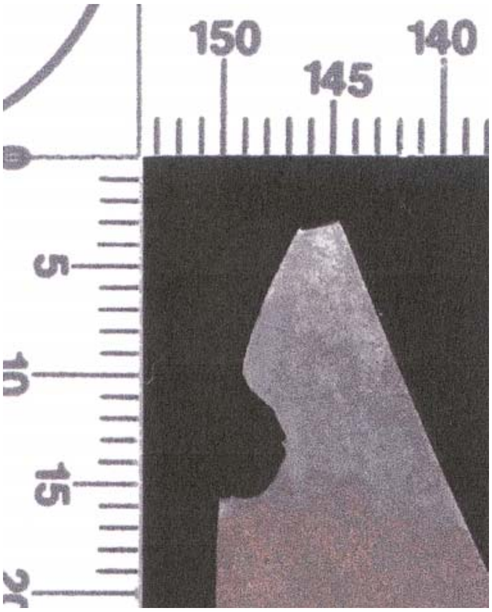

FIG. 3—*Part of the knife accidentally broken during the experiment and left in the bone (see Fig. 8).*

FIG. 4—*Subsized and macerated bone sample.*

Micro-CT system is capable of examining samples with diameters from 4 to 40 mm; the corresponding examination resolutions are from 10 to 100 μm.

The analysis was performed by measuring distances and angles in the cross-section views of the reconstructed volume to display optimally the cutting plane of the knife. Using Impact View software (VAMP GmbH, Möhrendorf, Germany) the dimension of the entrance area on the bone surface, the depth, and the 3D volume of the injury could be measured (7,8). This data were compared with the knives.

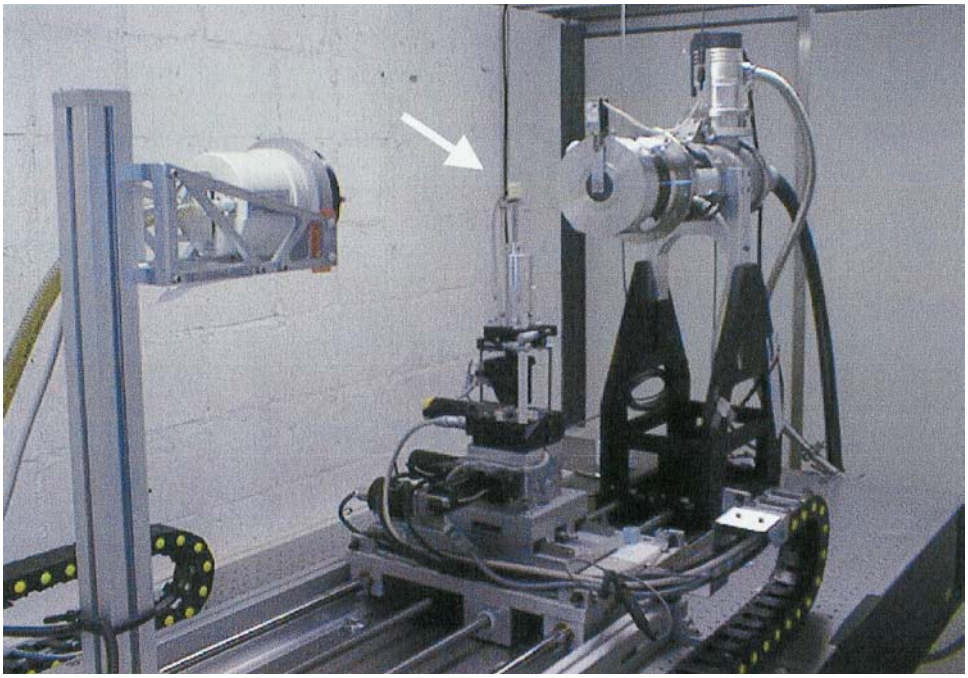

FIG. 5—*Micro-CT system with bone specimen (pointed to by the arrow).*

Results

The 3D Micro-CT volume datasets of the injured bone samples were used to obtain 2D slices (cross-sections) that optimally showed the cutting plane of wound profile of the knife (Figs. 6–8). The voxel size in the specific bone samples was 30 to 75 μm, depending on the sample size.

Based on the measured distances and angles of the injury in a 3D volume data set, it was possible to determine the size and shape of the injury-causing knife blade in the stab wounds. Figure 6*a–c* demonstrates an example of a perfect match at the tip of the knife blade. The small gaps between the periostal surface and the knife blade were caused by rotation of the knife when it was removed from the bone.

When the knife was rocked or twisted excessively when within the bone, a pattern was produced that did not correlate directly to the knife form. With this analysis, a plausible correlation is possible. As can be seen in Fig. 7*a–c* the movement of the blade can be visualized and a correlation to a particular instrument can be determined. By examining the wound profile and the tip of the knife (see accessorial dotted help line in Fig. 7*a* which indicates the status before dynamic rotation over the knife back) similarities are indicated. When the knife was rotated as it was removed (see arrow in Fig. 7*b–c*), the compact bone was fractured and the site of the entry was enlarged.

A broken knife tip can be graphically assigned to a suspect knife blade (Figs. 3, 8*a–c*): Fig. 8*a–c* shows an injury with rocking of the knife where a fragment of the blade was broken and forced into the bone. For visualization purposes, Fig. 8*a–c* show the cross-section where the fragmented parts of the blade were found. This does not coincide with the cross-section of the bone injury itself. Figure 8*a–c* show the mechanism of deposition of the broken blade fragments (red) in the bone during the removal of the knife.

Discussion

Radiography has assisted forensic science for over a century (14). Micro-CT is a specialized type of CT that can be used to examine compact bone and spongious trabecular architecture with high resolution (7,11–13). The non-destructive Micro-CT provides a much higher spatial resolution than the clinically used medical CT scanners. There are only a few papers in the literature concerning tool mark analysis in stab wounds to bone (2,4,6). Casting, impression production, and microtomic sectioning of bone to demonstrate sharp injury often do not produce accurate results. Micro-CT offers a new, non-invasive technique that documents bone structure with associated patterned injury. Micro-CT yields 10 μm resolution of 3D microstructures. With adequate viewing software, 2D slice data from an arbitrary plane can be extracted from 3D volume data sets. Using such software as a "digital virtual knife," the examiner can interactively section and analyze the 3D sample.

Analysis of the experimental study and the actual forensic case revealed that Micro-CT provides a very useful tool to narrow down the choice of knives that caused the bone injury. Even broken blade fragments could be graphically and non-destructively assigned to a suspect weapon. By using this microradiological method, it is possible to document "class characteristics" of the injury (general size, profile, shape, direction of travel/movement). Future studies with a higher spatial resolution Micro-CT may determine "individual characteristics" (caused by imperfections or irregularities on the surface of the implements) of a knife injury in bone. In the field of forensic pathology, Micro-CT provides a new and advantageous tool for non-destructive examination and analysis of patterned tool marks inside bone. By using the Micro-CT technology, we have described a new method for matching a possible injury-causing instrument against the patterned lesion inside the bone. In conclusion, we think that combining forensic

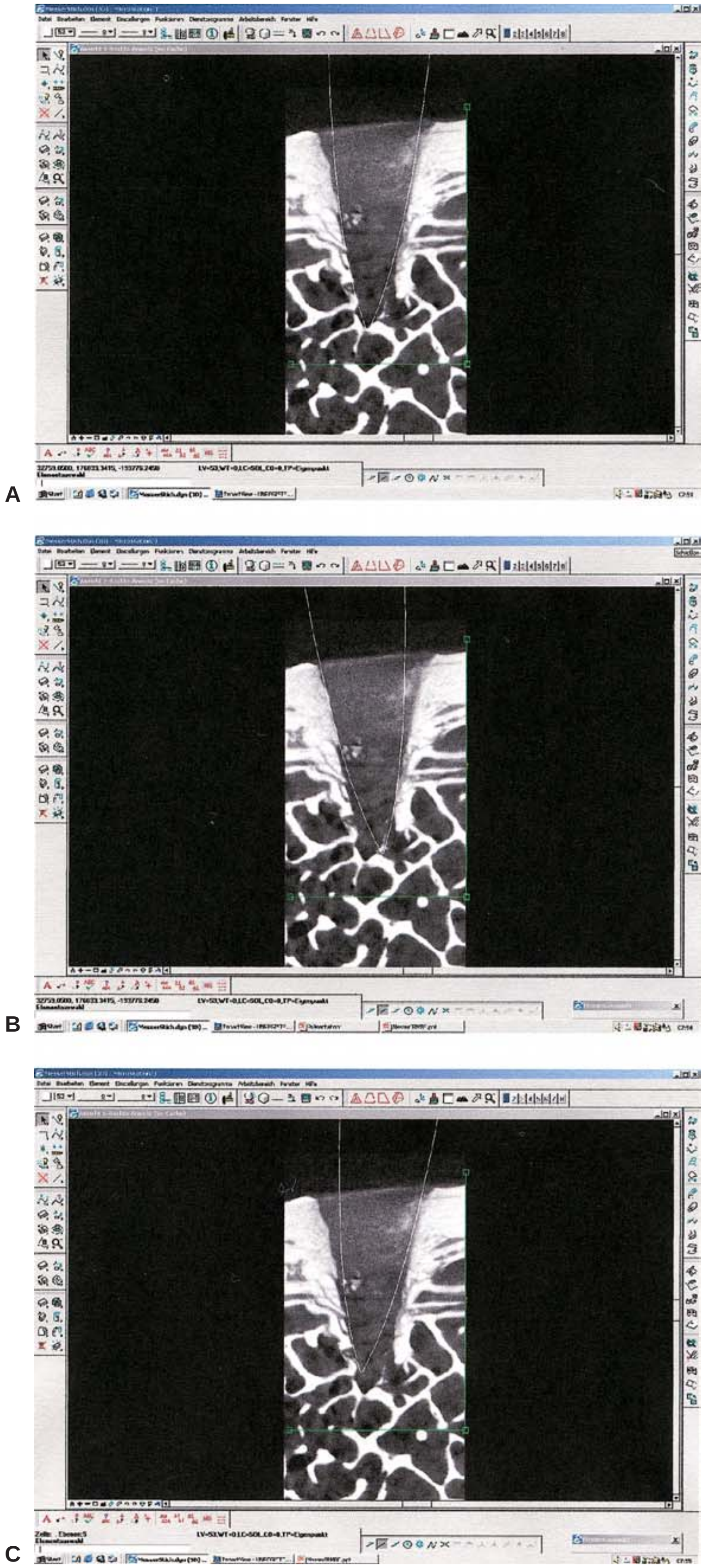

FIG. 6*a–c*—*An example of a straight knife penetration in the bone (see text for details).*

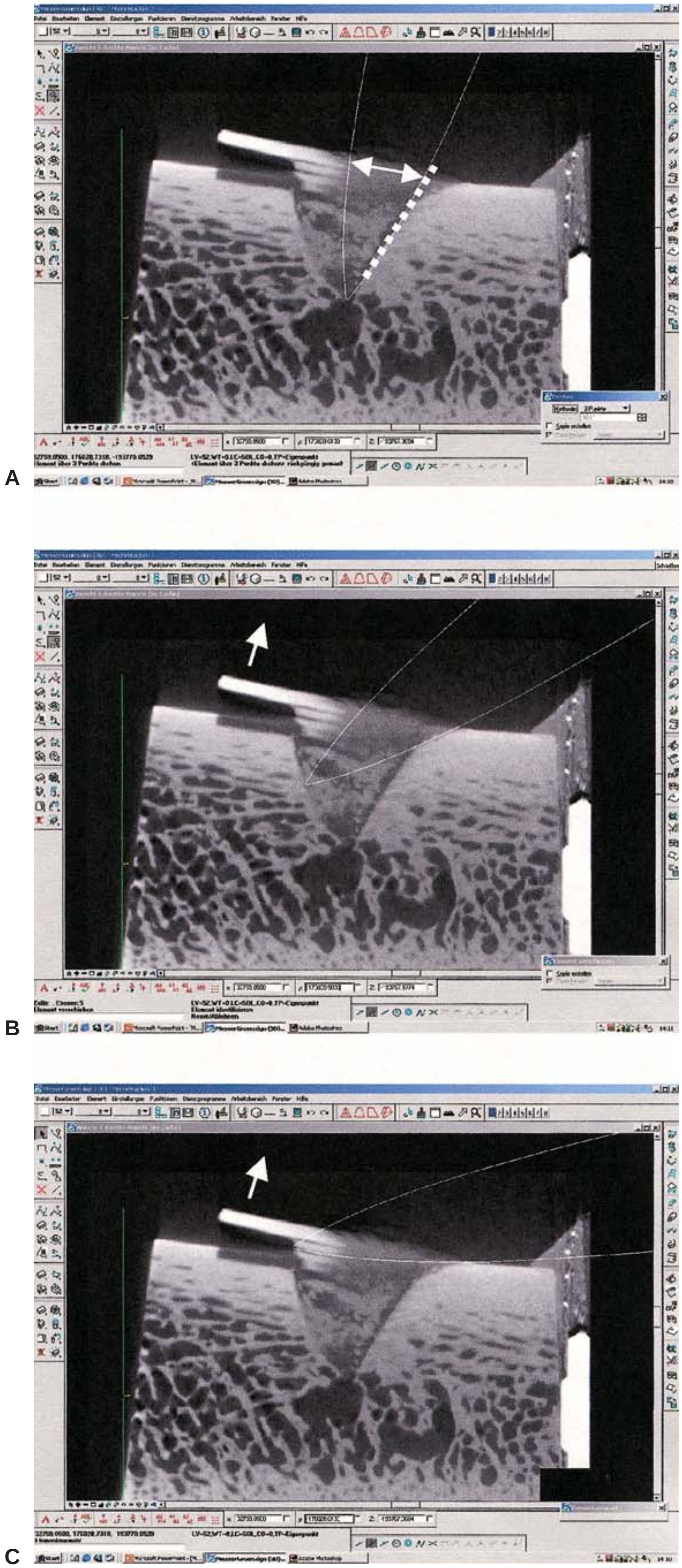

FIG. 7*a–c—A knife-induced injury with a rotational component (see text for details).*

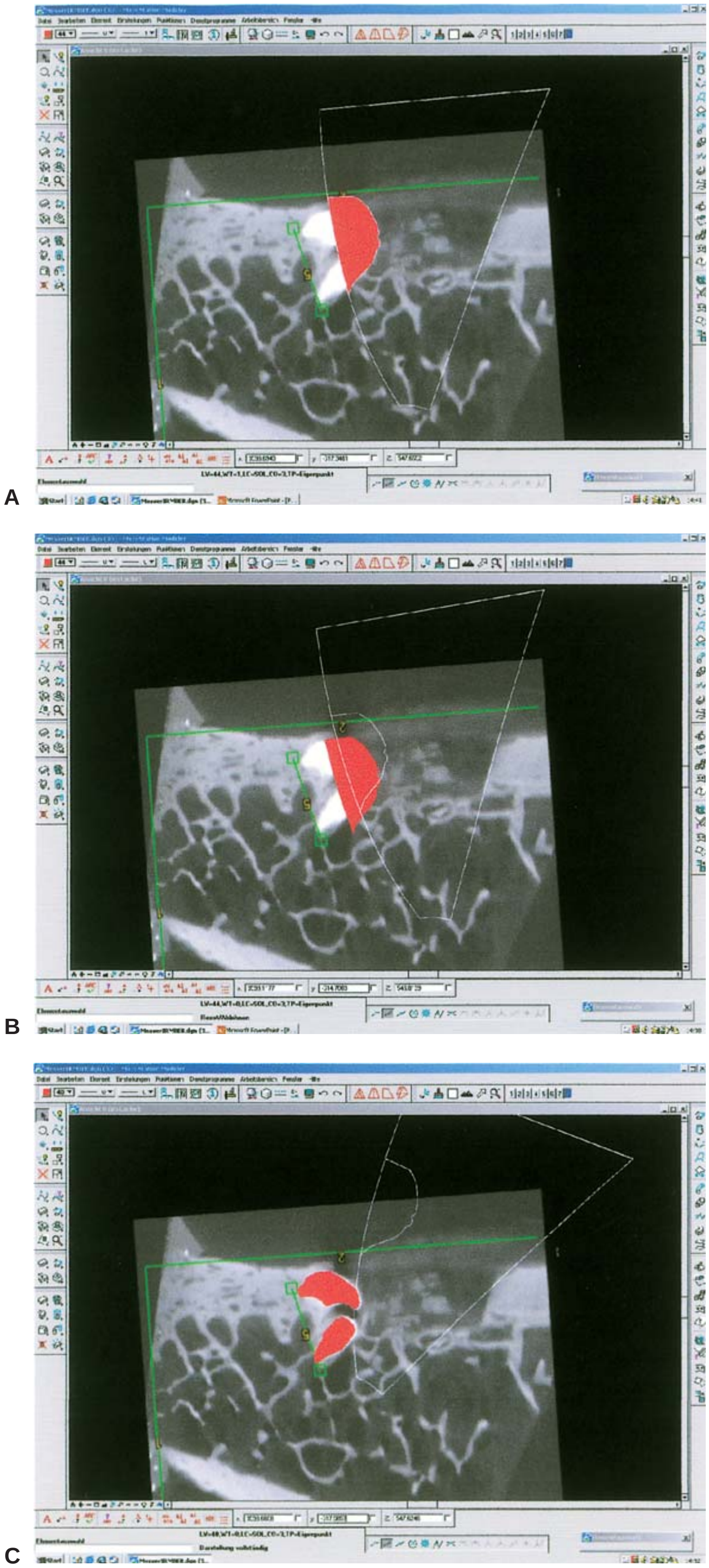

FIG. 8*a–c—Injury with a rotational movement where in addition, a fragment of the blade is accidentally broken and forced into the bone.*

pathology skills with high-technology imaging will open new horizons in forensic medicine and forensic science.

Acknowledgments

We thank Nicolette Scholz, Urs Koenigsdorfer, and Roland Dorn for their outstanding assistance during the experiments. Sincere appreciation is also expressed to William Oliver, Steve Symes, Kimberlee Potter, Cornelia M. Schwab, and Naseem Malik for their assistance in the preparation of this manuscript.

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