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Charred Body: Virtual Autopsy with Multi-slice Computed Tomography and Magnetic Resonance Imaging

ABSTRACT: The correct examination of a charred body is a forensic challenge. Examination, interpretation, and conclusion in respect to identification, vital reactions, toxicological analysis, and determining cause and manner of death are all more difficult than without burns. To evaluate what can be seen in the case of a charred body, we made an examination with the new radiological modalities of cross-section techniques, via multi-slice Computed Tomography (MSCT) and Magnetic Resonance Imaging (MRI), prior to performing the classical forensic autopsy. In a charred body case of a single motor vehicle/fixed object collision with a post crash fire, the radiological methods of MSCT and MRI made it possible to document the injuries caused by burn as well as the forensic relevant vital reactions (air embolism and blood aspiration). In conclusion, we think postmortem imaging is a good forensic visualization tool with a great potential for the forensic documentation and examination of charred bodies.

KEYWORDS: forensic science, forensic radiology, digital autopsy, virtual autopsy, virtopsy, Computed Tomography, Magnetic Resonance Imaging, burned, charred body

Although a fire generally does not completely destroy a body, in forensic pathology the correct examination of a burned or charred body is a challenge (1,2). It is expected to answer the questions in respect to:

1. Identification,
2. Vital reactions indicating that the decedent had been alive when the fire started,
3. The toxicological examination,
4. Cause of death and injuries, and
5. Manner of death.

The external surface of the body is often greatly destroyed, and visual identification, due to the damage caused by intensive heat and flame, is frequently impossible. Regardless of the severity of the superficial destruction, though, the teeth and organs of a body recovered from a fire are usually well preserved. Teeth and dental work are remarkably resistant to fire and can be used for a dental identification. Also, tissue and body fluids are usually available for DNA and comprehensive toxicological analysis, e.g., of carbon monoxide (CO), hydrogen cyanide from the burning, and also to differentiate between swallowed ethanol and other alcohols or substances created by the decomposition process.

Determining whether the injuries, resulting from heat or direct flame contact, occurred postmortem or while the victim was still alive requires great knowledge and experience on the part of the forensic pathologist. She or he will have to study the organs, the injury pattern, and the so-called vital reactions, and to combine them with the toxicological results in order to finally indicate the cause of death. The scene and criminal investigation, based on the cause of death, define the manner of death.

Following an old forensic rule, X-ray analysis of the entire burned body serves in locating foreign bodies and/or fractures (2). The application of radiological methods for the purpose of answering forensic questions dates back to the beginnings of X-ray diagnosis (3). The first radiological postmortem examination, in the context of an autopsy, took place in 1898, three years after the discovery of X-rays by Conrad Roentgen (3).

Classical radiography, based on the projection technique, reduces the 3D information of the body to a plane; due to superposition, exact three-dimensional localization of the structures or foreign bodies in situ is lost. Modern cross-sectional imaging techniques, above all multi-slice Computed Tomography (MSCT) and Magnetic Resonance Imaging (MRI) provide for a full body documentation with excellent spatial resolution in all three dimensions. We agree with Brogdon's (3) statement, "The sad truth is, that a century after the first X-ray was introduced as evidence in a court of law, there is no general appreciation of the extent of the radiology potential in the forensic sciences."

To evaluate the potential of MSCT and of MRI in the case of a charred body, we performed these two examinations and correlated them with classical forensic autopsy. In fact, we wanted to know whether the examination setup and techniques of MSCT and MRI, as used daily for the detection of diseases and trauma in the clinical setup, might answer relevant forensic questions in the postmortem examination of charred bodies.

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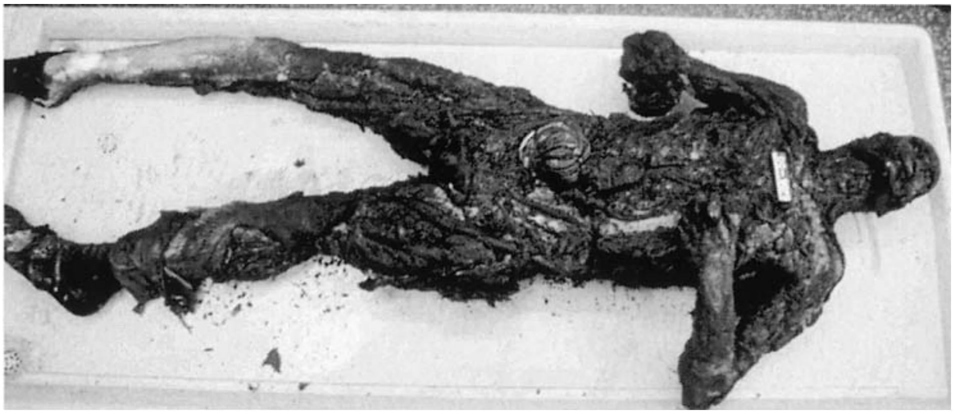

FIG. 1—*Charred body: victim of vehicle accident.*

This study was approved by the ethics committee and the responsible office of the justice department.

Methods

In a completely burned out car, next to a highway, a charred body was found on the driver's seat. The circumstances of the scene and the examination of the car suggested a fatal self -inflicted vehicle collision.

Radiological Examination with MSCT and MRI

The body was wrapped in two radiologically artifact-free body bags (Rudolf Egli AG, Bern, Switzerland). MSCT scanning was performed on a GE Lightspeed QX/i unit, and MRI scanning on a 1.5 Tesla Signa Echospeed Horizon unit (version 5.8, General Electric Medical Systems, Milwaukee, WI). In areas of forensic importance, axial MSCT was performed using a collimation of 4 × 1.25 mm; 950 axial cross-sections were calculated from the volume data. On a workstation (Advantage Windows 3.1, General Electric Medical Systems, Milwaukee, WI), sagittal and coronal reformations and three-dimensional reconstructions were then obtained. The duration of the MSCT scan was 10 minutes.

For MRI, we used a number of sequences, mainly T1-weighted SE, T2-weighted FSE (with and without fat saturation), STIR, and gradient echo or Flair. The MRI studies required 2.5 h. We acquired 600 MRI slices in different (axial, coronal, sagittal) planes. Image interpretation was performed by board-certified radiologists.

Autopsy

The autopsy was performed by board-certified forensic pathologists.

Radiological autopsy correlation

MSCT/MRI imaging and autopsy results were compared.

Results

Radiological Examination with MSCT and MRI

From the radiological MSCT data set the head was visualized in 2D and 3D (Figs. 3–7). On the workstation, soft tissues (Figs. 4, 6) were electronically eliminated, based on the difference in tissue densities. The result was a 3D presentation of the bony skull (Figs.

FIG. 2—*Burned head of the victim.*

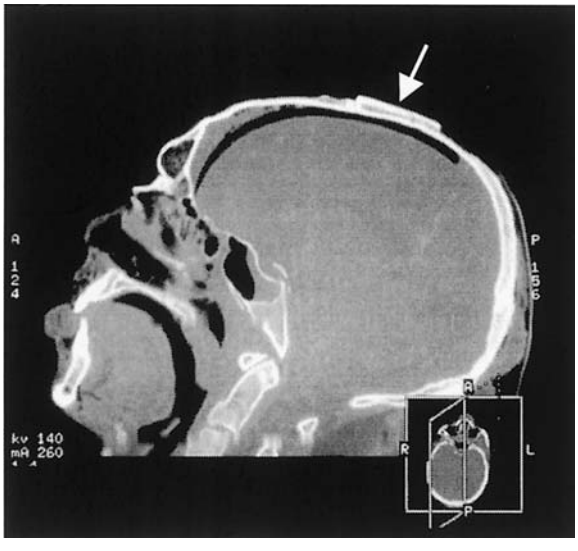

FIG. 3—*Reconstructed sagittal view of the MSCT data shows the not burned away part of the tabula externa (arrow).*

FIG. 4—*3D reconstruction from the axial MSCT data set visualizes the burned soft tissue (corresponding to Fig. 2).*

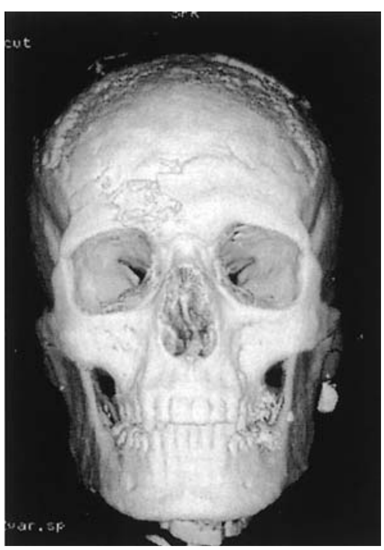

Fig. 5—*3D reconstruction from the axial MSCT data set visualizes the underlying bone structures.*

5, 7). The resolution of details by CT was good enough to depict clearly the burned away portion of the *Tabula externa* (Figs. 3, 7). In the sectional views, the expansion of the heat-caused epidural haematoma (the so called "heat epidural" (1,2)), which extends beyond the cranial sutures, was documented (Fig. 8—corresponding autopsy picture Fig. 9; "heat epidural" is also visible in the CT cross-section, see Fig. 3). There were no collision-caused fractures to the neurocranium. The heat-distorted brain parenchyma did not show traumatic injuries due to the accident. MRI pictures impressively documented the locally varying heat effects, with soft tissue being burned away particularly on the front of the body (Figs.10, 11). Also, intestinal protrusion from the abdominal cavity was documented (Fig. 11—corresponding autopsy picture Fig. 12). Despite several rib fractures, no large accumulations of fluid could be found in the chest nor the abdomen. The radiological images showed the presence of extensive gas embolism to the heart (Fig. 10) and liver. In the lungs, alongside a contusion of the anterior left

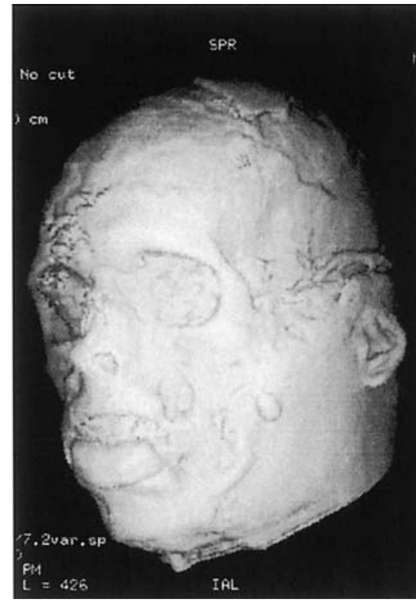

FIG. 6—*3D reconstruction shows the burned soft tissue in another view, even details such as the heat-shrunken left ear are visible.*

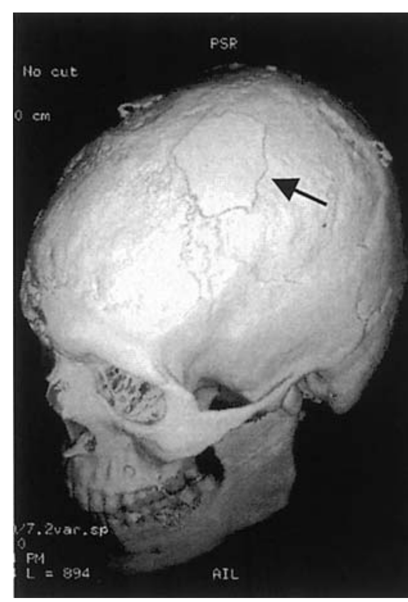

FIG. 7—*Corresponding bone reconstruction to Fig. 6 shows the not burned away part of the tabula externa in 3D.*

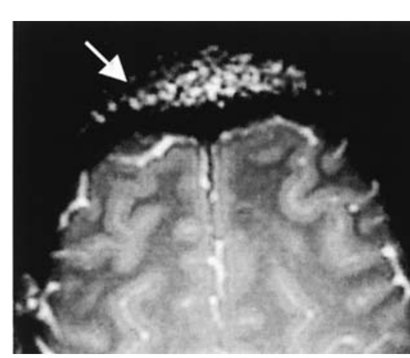

FIG. 8—*Virtual radiological autopsy MR cross-section shows the "heat epidural" (arrow).*

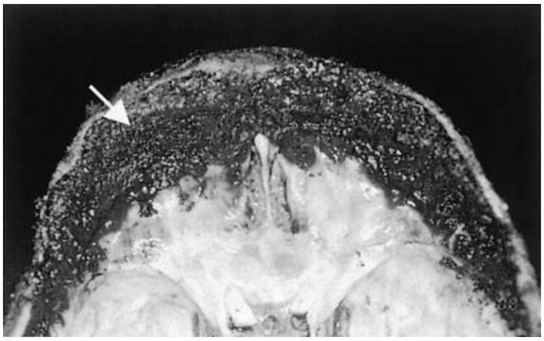

FIG. 9—*Corresponding autopsy picture to Fig. 8 shows the "heat epidural" (arrow).*

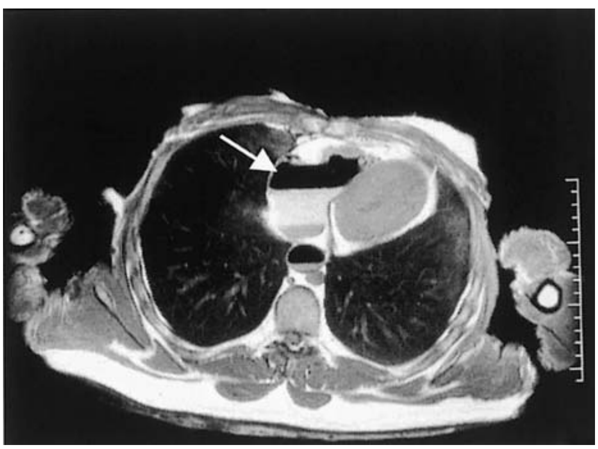

FIG. 10—*MR cross-section shows the air embolism in the heart (arrow) and the burned away soft tissue in front of the body.*

FIG. 11—*MR cross-section demonstrates the intestinal protrusion from the abdominal cavity (arrow).*

upper lobe, i.e., in the area of the vehicle's shoulder belt, extensive blood aspiration was discovered. The digital autopsy showed that the abdominal organs were relatively well preserved without traumatic findings. The cross-section imaging showed a collapse of the aorta.

Thus, male gender designation of the charred body was easy based on the pelvic MSCT/MRI sections.

The search for foreign bodies serving for identification, such as projectiles or surgical implants, was fast and the result unambiguously negative, except for dental work.

We documented traumatic fractures in the lower left leg (Figs. 13,14), which were not substantially heat-shrunken. In our opinion, this was the entrance of air into the systemic circulation.

Forensic Autopsy

Autopsy confirmed the above-mentioned radiological findings. Additionally, soot aspiration, a vital reaction, was discovered in the trachea and the esophagus. This finding had gone undetected in the radiological examinations. Many organs were pale, an indication of severe hemorrhage/exsanguation. The body was identified based on the dental work. The toxicological results showed only 6% carbon monoxide.

Discussion

Only the recent radiological development of cross-sectional imaging has allowed volumetric data sampling, an essential prerequisite for this study (4–11). Computed Tomography (CT) has

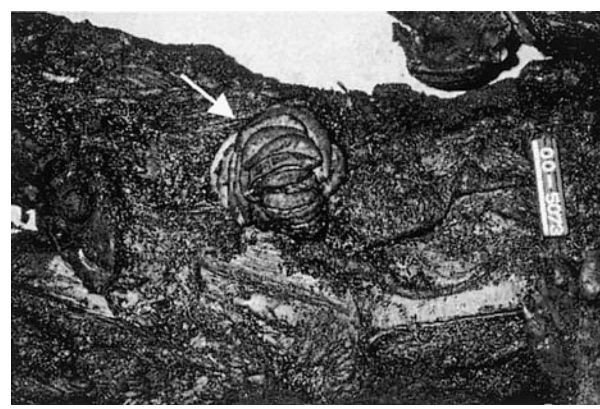

FIG. 12—*Autopsy picture corresponding to Fig. 11: intestinal protrusion from the abdominal cavity (arrow).*

FIG. 13—*3D reconstruction from the axial MSCT data set visualizes the fracture system in 3D (arrow).*

FIG. 14—*MR cross-section corresponding to Fig. 13 demonstrates fracture system (arrow).*

grown from initial single image translation-rotation scans—each lasting minutes for one axial image—to modern-day volume scanners using multiple detector arrays that make it possible to acquire multiple slices in less than a second. The introduction of the spiral CT technique in 1989 and the currently fourfold expansion of detector arrays (MSCT, since 1998) allow for rapid and isotropic documentation. MRI has followed a similar development, beginning with slow whole-body coils and weak gradients offering low resolution. Today we utilize high-field units with surface and phased-array coils as well as strong gradients offering rapid imaging sequences. Very high geometric and isotropic resolution can be obtained using 3D rather than 2D data acquisition.

Although both techniques (CT and MRI) have already been used in particular forensic cases (12–16), to the best of our knowledge, this is the first study that prospectively compares the full-body postmortem MSCT and MRI data with the forensic autopsy findings of a charred body.

We will discuss some issues relevant in forensic medicine of burned bodies and make the conclusion as to the benefits of documentation with MSCT and /or MRI.

Identification

The desiccation of skin and tissues, skeletal fractures and pulverization of the vertebral disks by the effects of heat completely alter the appearance and the length of the body (2). Visual or fingerprint identification is often not possible. Teeth, however, are often more resistant to fire than DNA material. But the conservation and examination of dental material at the scene and then in the morgue are often problematic (17). A mutilating procedure including disarticulation and excision of the upper and lower jaw is usually performed in supplement to a visual examination of the teeth. The ordinary axial cross-sectional MSCT technique is mostly unsatisfactory for documentation and identification of the victim in the presence of dental work, above all due to metal artifacts. A dedicated CT scanning technique (Dentascan^R, not utilized in this case, (18)), tailored to the teeth, their alveolar fixation and transplant planning, might be combined with metal artifact reduction algorithms (19, 20) and provide a non destructive documentation of the dental status in the near future. The current MSCT screening technique at least identifies implants, artificial joints, plates, metal staples, and foreign bodies related to the fatal mechanism, such as bullets. All these objects can be three-dimensionally localized within the body.

Radiological post-mortem data, combined with appropriate clinical data, often help the specialist to reach anthropologic conclusions with certainty, e.g., regarding the individual age of a burned or charred body.

We believe that in the near future an MSCT examination must be considered to compliment the autopsy of badly mutilated corpses, especially in mass disasters, such as aircraft crashes or burned buildings.

Vital Signs During Fire Exposure

To determine the cause of death it must first be established whether the victim was alive when exposed to the fire. Soot in the airways and the esophagus, as found at autopsy, was not detected by imaging methods in this case. However, CT proved vital reactions, such as air embolism to the heart and blood aspiration to the lung. Although gas release may be due to retraction of blood products or formation of coagulum secondary to heat effect, air embolism after traumatic fractures (e.g., of the lower leg) were previously observed by our group in other impacted body cases without heat influence. Nevertheless, we never observed air embolism in non-impacted fresh bodies. Of course, CT did not show the pale color of organs discovered during the autopsy, a sign indicating severe hemorrhage; whether a collapse of the aorta is a reliable sign of advanced hypovolemia, will have to be shown by more data.

Because the fat embolism syndrome with fat droplets in the pulmonary blood vessels can be observed either resulting from blunt trauma or from heat, the pathologic demonstration of fat embolism cannot be considered a proof of a vital reaction in burn victims.

Alcohol, Drugs, or Other Burn-Specific Analyses (Carbon monoxide, Hydrogen cyanide from Burning Polymers)

Because MSCT and MRI primarily are morphologic methods that show local lesions rather than altered chemical components of tissues, they are not expected to contribute much in this respect. Nonetheless, newer MR scanners also perform spectroscopic investigations, showing the relative tissue concentrations of several important chemical compounds (21). A non-contact, toxicological investigation of tissue and body fluids is conceivable in the future, even if it is not yet practicable. Another approach might be to gain needle biopsies and fluid samples under image guidance from any tissue or body location requested and to use them for highly specific laboratory analyses without cutting the skin and creating external wounds; this would help in countries where autopsy is religiously denied and therefore hardly ever performed.

Cause of Death and Injuries

It is often difficult to distinguish between a fracture due to heat exposure and one caused by physical trauma. Often there are artificial fractures to the skull. Flame contact with the exterior surface of the skull often causes local defects as a result of incineration of the external table and exposure of the spongy diploic layer of bone (1,2). Cracks in the skull during life are rarely limited to the external table. There are often "epidural haematomas" caused by heat, the so-called "heat epidurals": heat expresses clots of blood and marrow from the skull bone, and these accumulate between the undersurface of the bone and the dura mater (1,2). The clot-like structure must not be mistaken for an epidural haematoma sustained during life; it is differentiated by the fact that it does not stop at the sutures of the skull, in contrast to vital epidural haematomas. These findings are similarly documented by radiological methods and by autopsy. Splitting of the skin of a burn victim occurs in much the same way as heat fractures of the bones and might also be radiologically documented. Imaging methods are even better in localizing and reconstructing the intensity and direction of heat.

Our results are in complete agreement with the clinical experience that MSCT is the superb radiological method of documenting bone injury and gas embolism in the entire body. Because of its better tissue contrast MRI, is more suitable for soft tissue investigation, and this difference might be more critical in forensic medicine, due to the fact that contrast-enhanced MSCT is not feasible without an ongoing circulation.

Naturally and in agreement with the classical autopsy, the determination of the *manner of death* was not possible radiologically. The above findings and examination of the scene and the car revealed a fatal single vehicle accident as the cause of death.

In conclusion, we think that postmortem imaging is a good forensic visualization tool with great potential for documentation and examination of charred bodies.

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