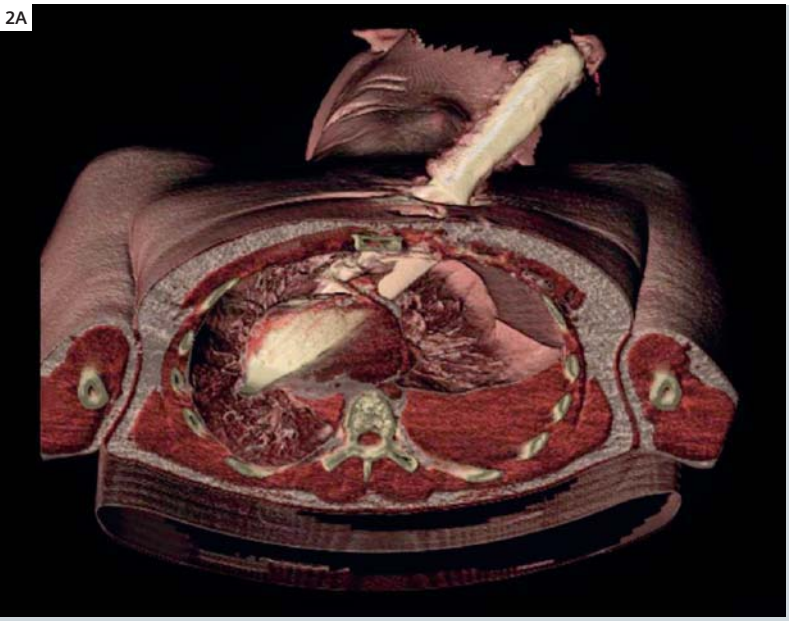

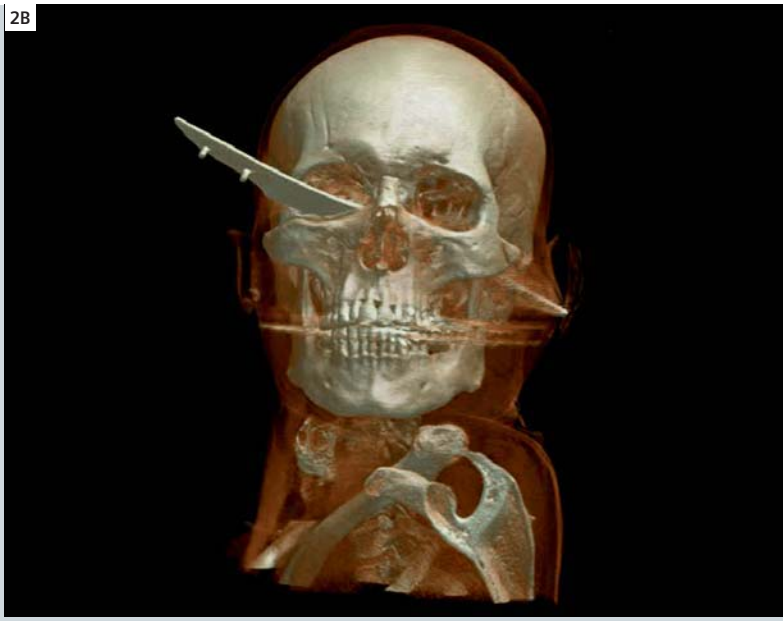

2 Alien objects exact location can be determined by DVR. Localization of a knife in a suicide (Fig. 2A) and in a murder case (Fig. 2B).

Virtual Autopsy in Forensic Medicine

The methodology of autopsy has not undergone any major transformation since the 19th century. But new radiological imaging methods such as multi detector computed tomography (MDCT) and magnetic resonance imaging (MRI) have the potential to become the main diagnostic tools in forensic pathology.

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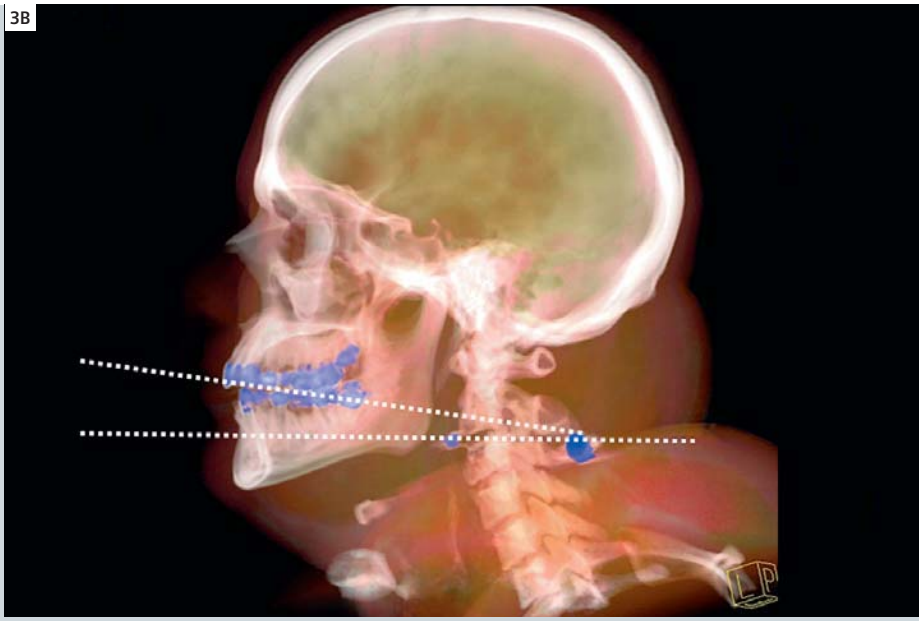
In forensic cases, the autopsy can provide vital information in criminal investigations. A recent addition to routine autopsy workflow is CT postmortem 3D imaging also known as Virtual Autopsy (VA). Excellent results are obtained using MDCT, DSCT or MRI data from scans of cadavers with direct volume rendering (DVR) 3D techniques[1]. The foundation of VA development is the modern imaging modalities that can generate large, high-quality data sets with sub-millimeter precision. Interactive visualization of these 3D data sets can provide valuable insight and enables non-invasive diagnostic procedures.

Several studies have shown the great potential of VA in forensic investigations[2–5]. There are many reasons for increasing interest in VA, for instance, they are time saving and can complement standard autopsies enabling broader and more systematic examinations. With VA, the body remains intact, avoiding objections by family members or religious communities and permitting additional analysis by other forensic pathologists on the same body, in effect, second or third diagnoses/opinions. Images and results of VA are understandable for jurors in



3 Small metal fragments in a burned victim (blue color, Fig. 3A). Bullet in the neck region (arrow, Fig. 3B), shot through the oral cavity.

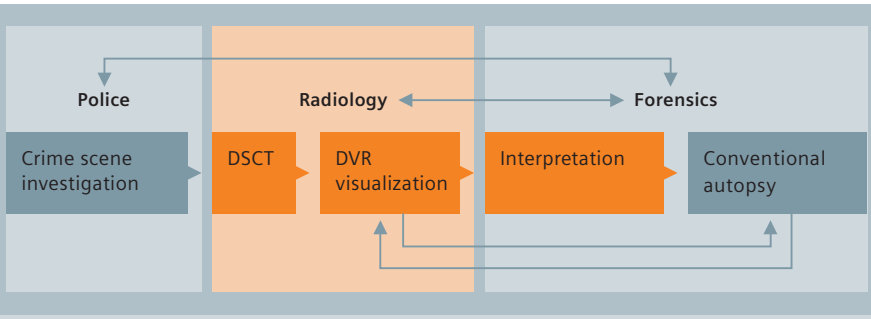
criminal cases. Furthermore infections that pose serious health risks for coroners, pathologists, and medical examiners can be avoided. And finally VA records can easily and conveniently be stored indefinitely.

The Virtual Autopsy Procedure

Autopsy procedures at the Center for Medical Image Science and Visualization (CMIV) in Sweden have been developed in collaboration with the Swedish National Board of Forensic Medicine. These procedures are now routinely used for forensic examinations and have been applied in over 200 (mostly murder) cases. The research and development has focused on the efficient workflow for post-mortem CT and on developing software that can visualize full-body datasets that could previously be viewed only in separate parts with limited interactivity [8].

A SOMATOM® Sensation 16-slice configuration was initially used. Since September 2006 a Dual Source CT scanner (SOMATOM® Definition) has been in service with even better results.

The workflow of the forensic procedure at CMIV is summarized in Fig. 1. The traditional autopsy is supplemented by adding the VA information shown in red. In most cases, the forensic pathologist comes to the crime scene and oversees the handling of the cadaver, which is placed in a sealed body bag before being transported to the forensic department and put into cold storage. The following morning, a full-body DSCT scan is performed in a few seconds. The radiologist and the forensic pathologist quickly obtain a clear survey of the entire body and can use volume rendering transfer functions (TF) to select aspects of the body, such as the skeleton to localize fractures. The full-body procedure permits fast localization of foreign objects such as metal fragments or bullets (Figs. 2A–2B, 3A–3B). This can provide essential information in the early part of the police investigation. Another important aspect is the high resolution of the data that allows details, such as dental information to be extracted for identification purposes. Another important feature is that the captured DSCT data are digitally stored, which enables the information to be re-examined as often as necessary. Frequently findings during the physical autopsy lead to new questions that the VA can answer [9–14]. Moreover, in crime



1 Overview of the forensic autopsy procedure at CMIV. Virtual autopsy activities, shown in red, are added to the traditional workflow and enable an iterative approach. This gives the investigators time to complete the crime scene investigation before the physical autopsy. The procedure is based on a continuous interaction between the forensic pathologist, the radiologist, and the police.

scene investigations, new findings may require other hypotheses to be scrutinized by postmortem imaging. As mentioned, VA is currently used as a compliment to the standard autopsy procedure. The time needed for the DSCT scan and visualization session is short in comparison to the physical autopsy and can make the autopsy more efficient because the pathologist has prior knowledge of the case before conducting the standard autopsy. That the cadaver remains in a sealed body bag throughout the VA procedure also preserves technical evidence, such as fibers and body fluids, which in forensic cases are of great importance.

The use of Dual Energy CT for VA.

Dual Energy CT (DECT) with two X-ray sources running simultaneously at different energy levels, can acquire two data sets showing different attenuation levels, thereby obtaining additional information about the elementary chemical composition of the scanned material. Color can then be assigned according to the value differences between 80 kV and 140 kV. Such a color-mapped, dual energy image can differentiate, for example, between calcifications and Iodine contrast (Fig. 4). This technique can be used, for instance, for direct subtraction of bone from the CT raw data – without post processing – to better visualize blood clots in vessels and possible bleedings in soft tissue[15], and to facilitate classification of different tissue types such as tendons and cartilage. DE makes CT an even more effective VA tool (Figs. 5–6)[15].

The future for virtual autopsies?

To improve the forensic value of Virtual Autopsy (VA) with CT, a VA workstation needs to be implemented. Visualization tools to increase quality and efficiency of the virtual autopsy procedures need to be developed that specifically address forensic questions. And designated protocols for the main forensic case categories should be established.
Data analysis research includes the implementation of computer aided diag-

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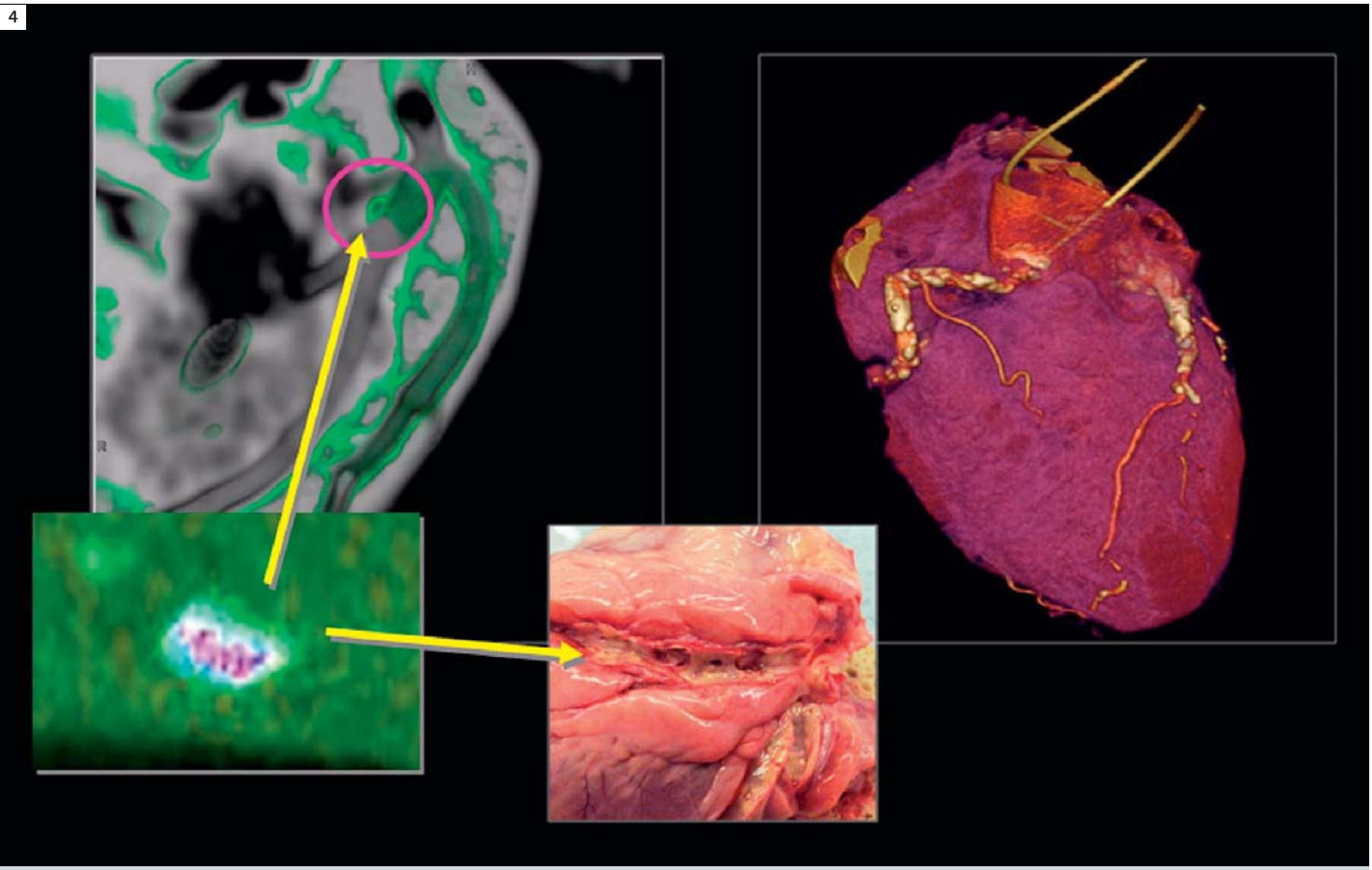
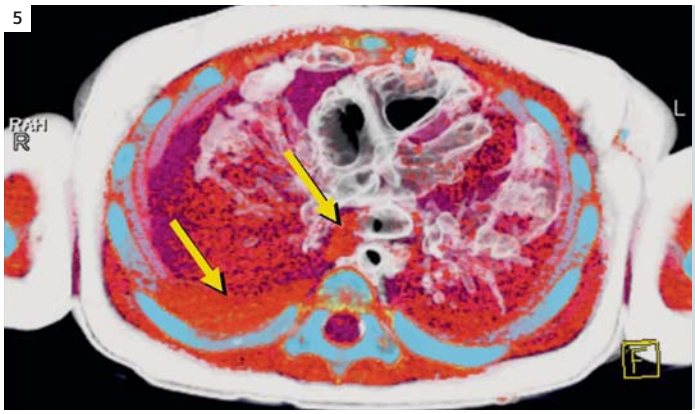
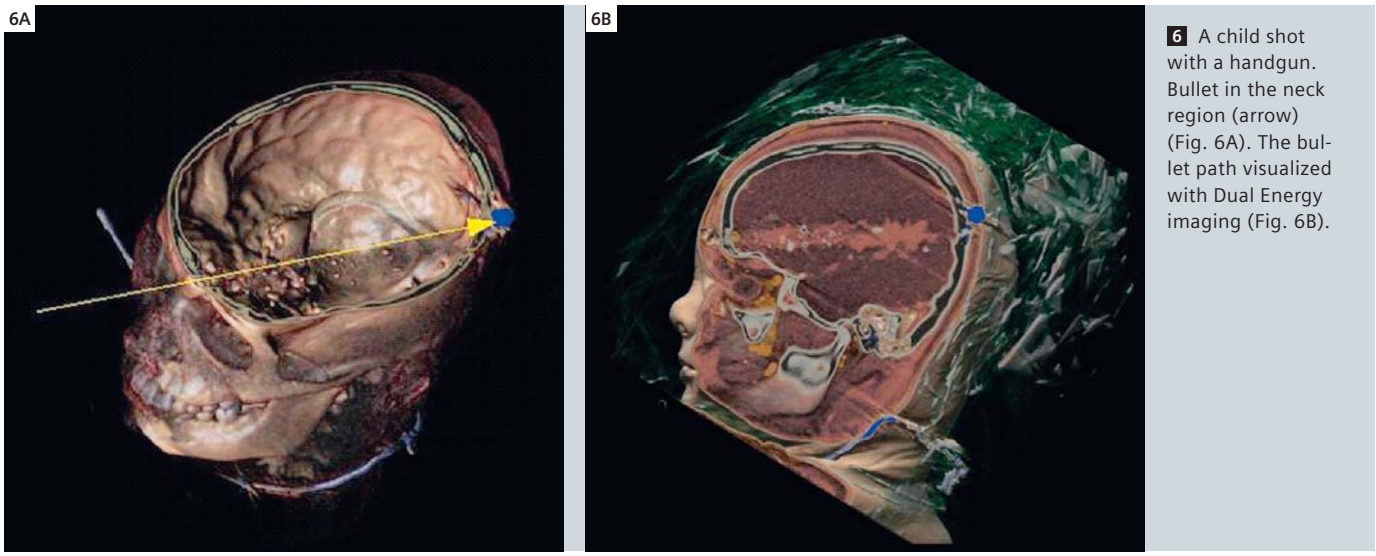


4 An Ex-vivo DSCT angiography of the heart with DVR can give an excellent anatomic visualization of the coronary arteries. Vascular pathologies such as calcification, stenosis and soft plaques can be detected. In this case iodine contrast has been injected through plastic tubes inserted into the coronary arteries. Vessel wall plaque can be visualized with Dual Energy imaging.



5 Dual Energy images. Hemosiderin is visualized in red and bleeding can be seen in the right pleural cavity and to the right of aorta (arrows).

nostic tools that can, once applied on the post mortem volume data, help to search for relevant forensic findings, characterize them and deliver general information of the deceased individual such as body height, weight, sex, major injuries, foreign bodies (e.g. projectiles) and likely causes of death in an automatically generated, preliminary written virtual autopsy protocol.
This would allow for virtual autopsies to be performed in large numbers within a reasonable time frame to handle incidents such as the Tsunami catastrophe in Asia 2004, where no autopsies were performed at all.
For a new era of digital autopsies to truly emerge, many social, legal, medical and technical areas must work in unison. Medical professionals and legal authorities must determine standard protocols for scanning and storing data. Legal systems around the world must accept the admissibility of imaging evidence. And as a new field, postmortem radiology will require special training and knowledge. Radiologists are trained to interpret images of living patients, but the dead often look different. For example, severe trauma or the effects of decomposition can displace organs. Understanding these differences will require knowledge and expertise that does not exist on a widespread basis today. Invasive autopsies will remain the norm for at least the next few years. But, as knowledge and acceptance increase, traditional autopsy can gradually be replaced by a non-invasive virtual autopsy, and, when necessary, minimum invasive image-guided tissue sampling can be taken. Postmortem VA has the potential to gain high acceptance in the population as well as in professional circles, making possible high levels of quality control in forensic medicine.



6 A child shot with a handgun. Bullet in the neck region (arrow) (Fig. 6A). The bullet path visualized with Dual Energy imaging (Fig. 6B).

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