Chapter 9
Virtopsy: The Virtual Autopsy*

9.1 Introduction

9.1.1 Preliminary Considerations

In forensic medicine, autopsy remains the gold standard for determining the cause and manner of death. An autopsy consists of two parts. First, an external examination is performed, in which all external findings are documented with photographs and in a written report. Second, the body is opened for the internal examination. All organs are removed, inspected, measured, and sampled for histology, in order to identify pathologies that lie within the organs. All internal findings are added to the written report.

This approach has some disadvantages. Due to its invasiveness, important evidence can be destroyed. In cases of advanced decomposition, liquefied organs lose their structural integrity if their surrounding body cavity is opened. Additionally, some cultural and religious belief systems prohibit the autopsy procedure.

The quality of the final report highly depends on the skills of the investigator to find and appropriately describe the findings. Findings that are overlooked, or conclusions that are poorly formulated, translate into a loss of evidence, that cannot be corrected once the body is buried.

The Virtopsy project began in 2000, at the Institute of Forensic Medicine of the University of Bern, in Switzerland. Its aim is to apply high tech methods from the fields of measurement engineering, automation and medical imaging to create a complete, minimally invasive, reproducible and objective forensic assessment method. The data generated can be digitally stored or quickly sent to experts without a loss of quality. If new questions arise, the data can be revised even decades after the incident.

In the rest of this chapter, the techniques used in the Virtopsy procedure are described, including: post-mortem computed tomography (PMCT) and post-mortem computed tomography angiography (PMCTA), post-mortem magnetic

*This chapter is contributed by Lars C. Ebert, Thomas Ruder, David Zimmermann, Stefan Zuber, Ursula Buck, Antoine Roggo, Michael Thali, and Gary Hatch.

E. Nissan, *Computer Applications for Handling Legal Evidence, Police Investigation and Case Argumentation*, Law, Governance and Technology Series 5,
DOI 10.1007/978-90-481-8990-8_9,

resonance imaging (PMMR) and minimally invasive tissue and liquid sampling as means for documenting internal findings. These results can be combined with and surface scanning and photogrammetry which document the external findings. Following the introduction of the techniques, we explain the different ways of presenting the data, depending on the audience. Finally, the impact and acceptance of Virtopsy within the Swiss justice system is discussed.

9.1.2 Indications for Virtopsy

The Virtopsy approach is applied to a majority of the cases that undergo forensic evaluation at our institute. The additional information acquired through postmortem imaging prior to autopsy is often used to plan the autopsy, confirm autopsy findings and allow for a second-look if further questions arise in during the forensic investigation.

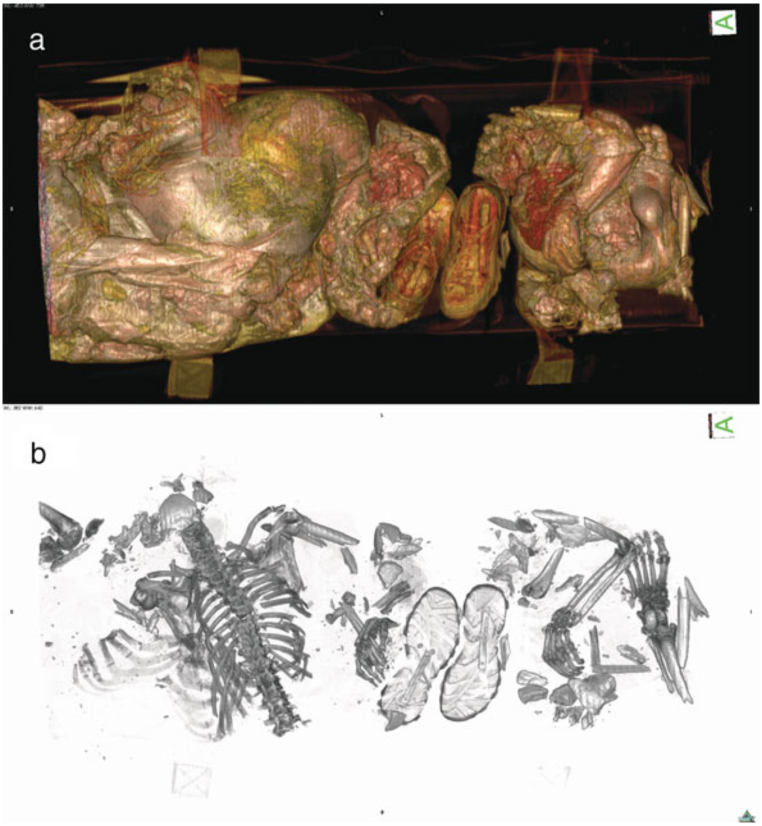

Fig. 9.1.2.1 Volume reconstructions of a CT scan of a train suicide victim (Osirix, Osirix foundation, Switzerland). (**a**) Surface reconstruction. (**b**) Bone reconstruction for quick assessment of the completeness of the body

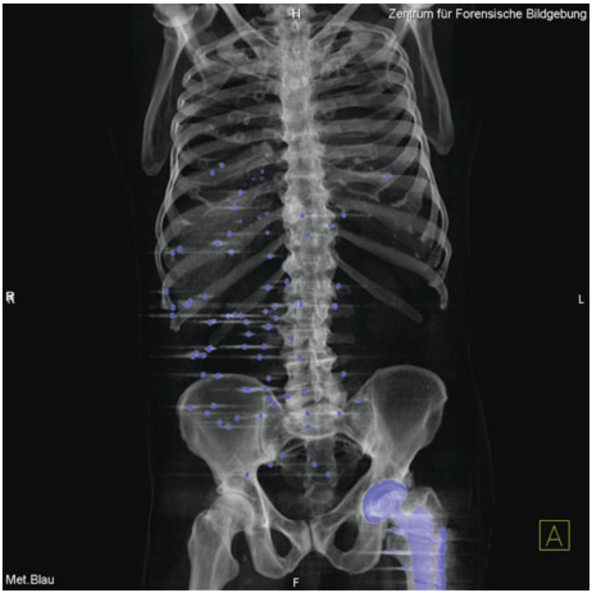

Fig. 9.1.2.2 Volume rendering of a gunshot victim (Leonardo, Siemens, Germany). Highly x-ray dense materials such as the shotgun pellets and artificial hip joint are automatically color coded to aid with better perception

In all cases of uncertain or unknown identity, the whole corpse of the decedent is scanned for radiologic identification through comparison of ante-mortem data with post-mortem CT. In the case of train-pedestrian incidents, CT data is useful to identify missing organs or skeletal parts (Fig. 9.1.2.1). Additionally, CT is able to detect and, depending on the density of the object, identify foreign bodies such as medical implants (useful for identification) or projectiles and bullet fragments (relevant to the forensic investigation) (Fig. 9.1.2.2) . All homicides, deaths under the age of 18 years of age, and complicated cases are also evaluated with the Virtopsy method.

9.2 Technical Aspects of Virtopsy: Imaging Modalities and Techniques

9.2.1 The Virtobot System

Some tasks in forensic imaging are either repetitive or require a high accuracy. Automation could help to increase the quality of examinations and reduce costs. At the Institute of Forensic Medicine in Bern, we developed a robotic system to satisfy these needs. The so-called *Virtobot* (Ebert et al., 2010) is a 6-axes industrial robot, that is mounted onto an external axis along with the computed tomography couch (CT couch), so it can access the entire scannable volume (Fig. 9.2.1.1). It has a changeable end-effector and can therefore mount different tools. We incorporated a surgical navigation system to allow for a closed loop robot control. Currently modules for automated surface scanning and minimally invasive biopsy exist.

Fig. 9.2.1.1 *Right to left*: The Virtobot system with mounted surface scanner, optical tracking system for biopsy, CT scanner and heart-lung machine for post-mortem CT angiography

9.2.2 Photogrammetry and Surface Scanning

The exact three-dimensional recording of the body surface with all injuries as well as the documentation of suspected injurious objects (Thali, Braun, & Dirnhofer, 2003) – including for example vehicles – is carried out with the GOM TRITOP/ATOS III System (Gesellschaft für Optische Messtechnik mbH, Germany). This system delivers a high resolution, three-dimensional scan of the object. It can be employed for true-color 3D digitizing of smallest injuries as well as larger objects such as cars or trucks.

GOM TRITOP is an industrial optical measuring system, based on the principle of digital image-photogrammetry (Luhmann, Robson, Kyle, & Harley, 2006).[1] It is used for full-automatic, highly accurate measurements of 3D coordinates of discrete object points.

The flexible GOM ATOS III optical measuring machine is based on the triangulation principle. Two cameras observe striped patterns projected onto the object.

[1] Luhmann et al. (2006) is a standard reference on close range photogrammetry, "which uses accurate imaging techniques to analyse the three-dimensional shape of a wide range of manufactured and natural objects. Close range photogrammetry, for the most part entirely digital, has become an accepted, powerful and readily available technique for engineers and scientists who wish to utilise images to make accurate 3-D measurements of complex objects" (ibid., from the blurb). The mathematics of close range photogrammetry handles orientation, digital image processing, and the reconstruction of a model in three dimensions. Imaging technology includes both hardware and software. Important topics include targeting and illumination.

Up to four million highly precise 3D coordinates are then calculated from each single measurement. The measurements from different views are transformed into one coordinate system using reference targets to capture the whole objects surface. Next, a high resolution polygon mesh of the object surfaces is generated.

In forensic applications the color information of the measured object is very important for further analyses. The corresponding color value from the photogrammetric recordings is assigned in the TRITOP software to each point of the 3D surface model created in ATOS, resulting in a colored 3D model of the object.

For optimizing work flow, the surface scanner can be mounted to the Virtobot system and from there, it digitalizes the body surfaces of the deceased automatically. This system significantly decreases scanning times and only one operator is required. By using automation, a constant quality of the scans can be maintained, since the process is operator independent. A module for automated photogrammetry is currently in development.

9.2.3 Post-mortem Computer Tomography (PMCT)

9.2.3.1 CT Scanners

A CT scanner makes measurements of the x-ray attenuation through a predefined plane of a cross section of the body. The resulting dataset is a 3D volume consisting of volume pixels (voxels). In helical CT imaging, an x-ray tube rotates around the body, while the body is continuously moved through the gantry (Kalender, Seissler Klotz, & Vock, 1990). Since the resulting data are a set of 2D projections, the x-ray density of each voxel is then calculated by using filtered backprojection. The resulting voxels contain the information about the attenuation of x-ray that is displayed as density, measured in Hounsfield units (HU). 0 HU have been defined to be equivalent to the density of water, –1000 HU (i.e., one thousand below zero) to the density of air. The density of all other organic and inorganic materials vary individually and are used to distinguish between different tissues. On regular CT scanners HU range from –1000 to +3070, but the upper limit may be extended to be +30710 HU. Multislice scanners have a row of several detectors to decrease scanning times and therefore motion artifacts. Dual Source CTs make use of two perpendicular x-ray sources with different energy levels and allow for better differentiation of dense materials.

Typical resolution achieved with standard CT scanners is about 0.5–1.5 line pairs/mm. This means that objects of about 0.5 mm can be discerned. Standard postmortem full body CT scans with a slice thickness of 1.25 mm and an increment of 0.7 mm consist of around 1500 single images (512*512 pixel in plane resolution).

The fact that CT imaging is based on x-ray attenuation allows for excellent assessment of osseous lesions such as fractures, collections of gas such as vascular gas embolism or detection of foreign bodies. The comparison of individual HU values of different foreign bodies may assist to identify if a given foreign body is metallic or non-metallic. Three dimensional image reconstruction software applications such as multi planar reformation (MPR) can display gunshot wound trajectories. The assessment of organ injuries with CT falls short of the sensitivity and specifity of MR imaging or autopsy, however, large organ lacerations can be detected. The volume of a fluid or gas collection can be measured (Jackowski et al., 2004) and the weight of organs can be estimated (Jackowski et al., 2006) based on voxel size.

9.2.3.2 Identification by Means of CT Scanning

CT scanning is a common examination performed in clinical radiology, which provides an ample pool of ante-mortem studies for use in cases of unknown identification. With the increased use of medical imaging techniques in clinical medicine, an increasing number of ante-mortem datasets is available. Prominent landmarks in these scans, such as the paranasal sinuses, but also medical implants such as dental implants, bone screws and plates, pacemakers and others can be used for comparison with post-mortem CT datasets for identification. By using maximum intensity projections, post-mortem CT datasets can be compared to ante-mortem 2D x-ray projections, or ante-mortem CT datasets. These techniques are reliable, even if the body has damages due to trauma or putrefaction. The advantages of these techniques are their quickness, reliability and low costs compared to other means of identification such as DNA analysis.

9.2.4 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is a medical imaging technique. In contrast to CT, MRI is not based on x-rays but uses a strong magnetic field. The strength of the magnetic field is measured in Tesla [T], and current MR units work with 1.5 T or 3 T magnets, creating a magnetic field that is roughly 50,000–100,000 times more powerful than the magnetic field of the earth.

In medical imaging MRI is based on the magnetization of hydrogen atoms in the body. Hydrogen atoms consist of a single proton and a single electron. When placed in a strong magnetic field, the protons of the hydrogen atom align themselves, similar to compass needles, along the axis of the magnetic field (B_0). In order to create an MR image, a short radio frequency (RF) pulse is emitted, altering the alignment of the protons by flipping the axis of the protons out of the magnetic field (B_0).

The time a given proton needs to realign along the axis of the magnetic field after the emission of a RF pulse is called spin-lattice relaxation time (T1). The RF pulse not only flips all protons out of the axis of the magnetic field, is also synchronizes the phase of each individual proton spin. The desynchronization of the spins after the emission of the RF pulse is called spin-spin relaxation time (T2). Tissue differentiation on MR images is based on the individual relaxation times T1 and T2 of different tissues.

MRI provides greater contrast for soft tissues than CT and is therefore useful for neurological, cardiovascular, and musculoskeletal imaging. In the post-mortem setting, MRI is a powerful adjunct to CT, its ability to visualize soft tissue organs complements the ability of CT to visualize osseous lesions.

However, there are a few important differences between ante-mortem and post-mortem MRI. The absence of motion artifacts in the post-mortem setting allows for better depiction of anatomical details. The assessment of the cardiovascular system in living patients, involves not only the morphology but also the function of the heart – an aspect that obviously cannot be evaluated in post-mortem MRI. After the cessation of cardiac motion, gravity causes fluids to pool in the dependent parts of the body and the corpuscular elements of fluids, such as blood cells will sediment within the vascular bed. The relaxation times T1 and T2 are both temperature dependent and image contrast may change with decreasing body temperature of a decedent (Fig. 9.2.4.1).

Also note the following shortcomings or limitation:

- With respect to CT, MRI is more time consuming and the time needed for post-mortem MRI may vary significantly, ranging from less than 1 h for focused regional imaging to several hours for whole body MRI.
- MRI scanning is limited to cases that do not involve metallic fragments or MRI incompatible implants. A prior CT scan can help to search for these types of foreign bodies.

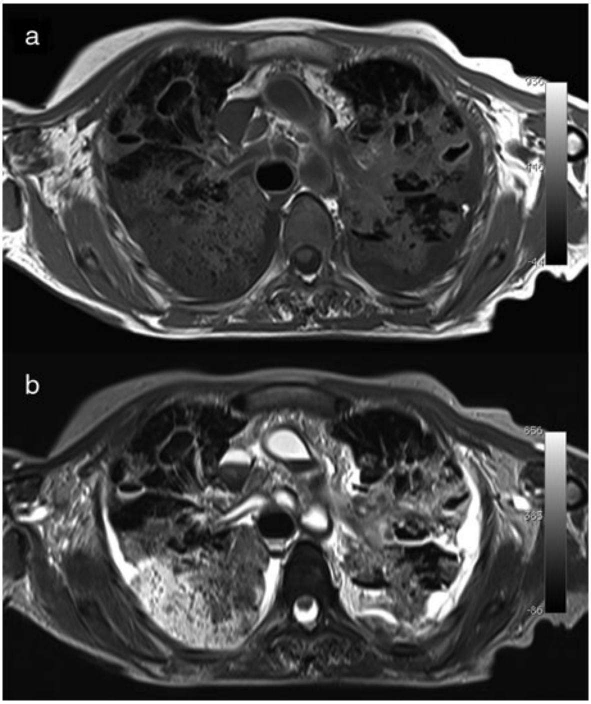

Fig. 9.2.4.1 Two different MRI scans showing a case of tuberculosis. (**a**) T1 weighted scan with bright fat and dark water content. (**b**) T2 weighted image with bright water content

9.2.5 *Post-mortem CT Angiography*

The assessment of the vascular bed and lesions of the vascular bed in non-contrast CT studies is very limited. In living patients the visualization of the vessels is achieved by intravascular injection of a contrast medium. The blood circulation distributes the contrast medium to the peripheral vessels and the internal organs, before it is excreted through the kidneys.

For the post-mortem setting, a non-dynamic CT angiography has been developed using the roller pump of a modified heart-lung machine to distribute the contrast medium in the vascular system. Vascular access is gained through a cut-down at the level of the femoral vessels.

- For visualization of the arterial system, a tube is inserted into the femoral artery and contrast medium is injected at a constant pressure. A second tube is inserted in the femoral vein, to drain and collect the overflowing blood from the venous system. Imaging is performed immediately after the instillation of the contrast medium.
- For visualization of the venous system, the injection and drainage tube are simply switched and the procedure and imaging are repeated.

Fig. 9.2.5.1 Volume reconstruction of a CT angiography (Osirix). The surrounding tissue has been virtually removed to expose the arterial system. This image shows a case of aortic dissection

In contrast to ante-mortem angiography, an important portion of the fluid components of blood have leaked out of the vessels and sedimented into the dependent portions of the body. This fluid has to be replaced for the post-mortem angiography and the contrast medium is therefore diluted with a high molecular hydrophilic or lipophilic solution:

- polyethylene glycol (PEG), discussed by Ross et al. (2008),
- or diesel oil, discussed by Grabherr et al. (2006).

Using a high molecular solution rather than a small molecular solution as a volume expander for the contrast medium, prevents leakage out of the vessel wall and subsequent edema.

Post-mortem CT angiography allows for excellent visualization of the entire vascular system of a decedent (Fig. 9.2.5.1). Vascular injuries and extravasation of contrast medium can thereby be diagnosed based solely on imaging. Intraabdominal or thoracic hemorrhages can be traced back to the lacerated vessel/s. Small vascular lesions that can be difficult to visualize during autopsy, may be identified after CT-angiography.

9.2.6 Tissue/Liquid Sampling

In order to define pathologies on a cellular level, a histological examination on tissue samples can be performed. For this technique, the tissue sample is sliced, stained and evaluated under a microscope. During autopsy, a tissue sample is retrieved by cutting a piece from each organ. Apart from the invasiveness of this approach, the quality of the samples is relatively poor, since it can be contaminated with other tissues or body fluids. Several techniques for minimally invasive tissue and liquid sampling have been developed or adapted from clinical medicine by the Virtopsy group.

The standard procedure for minimally invasive sampling involves placing an *introducer needle* to the exact location the tissue sample should retrieved from. A biopsy gun retrieves the tissue sample though the introducer needle. Three methods to place the introducer needle have been used at our institution: CT guided, navigated, and robotic needle placement.[2]

- In CT guided needle placement, the needle is placed by a radiologist under real-time fluouroscopic guidance inside the x-ray beam. Since CT only displays one slice of the body, accurate needle placement is limited by the possible gantry

[2] CT guided need placement is discussed in Aghayev et al. (2007). Navigated needle placement is discussed in Aghayev et al. (2008). Robotic needle placement is discussed in and Ebert et al. (2010).

tilt. Additionally, it comes with radiation exposure for the radiologist. These problems lead to the implementation of a technique based on surgical navigation.

- In surgical navigation, arrays of infrared markers are attached to every tool and anatomic structure that should be navigated. A tracking system then accurately determines the three-dimensional position of each marker. Based on this information and a CT dataset, a computer system tells the user where the needle is in 3D space, relative to a defined target, and guides the user to the target. This method works without radiation exposure to the radiologist, but requires training and skill on the part of the operator.
- In order to completely eliminate the human factor, a biopsy module was developed for the Virtobot system. It can automatically and precisely place introducer needles based on trajectories planned with CT data.

9.2.7 Virtopsy Workflow

The workflow of a Virtopsy is case specific. Depending on the individual case history, the Virtopsy team decides what image modalities are required to answer the forensic questions concerning the cause of death (Fig. 9.2.7.1). In forensic cases where the body displays patterned injuries or if reconstructive questions are opened, a colored 3D documentation of the body surface is recorded.

Using the Virtobot system, the entire body is documented with photogrammetry and surface scanning. Two scalebars and An array of optical and radiopaque markers are applied to the body. For the following photogrammetry, a series of photographs are taken from different positions. The TRITOP software automatically processes the photos and calculated the exact 3D coordinates of the uncoded reference markers as well as the camera positions. This data is exported to the surface scanners ATOS software to subsequently perform the surface scan of the object. Furthermore, the photographs are used for texturing of the surface model. If the Virtobot is used for scanning, the robotic system approaches different predefined positions in space and the attached surface scanner measures the topology automatically. In order to get a complete scan of the body, it has to be turned from supine to prone.

After external documentation, a CT scan is performed. Since the radiopaque markers are visible in the surface scan as well as the CT scan, data from both modalities can be merged into one set of data. In case of suspected vascular injuries or internal hemorrhage, a CT angiography is performed after accessing the femoral arteries and connecting the heart lung machine.

If the body has shown to be free of ferromagnetic foreign bodies such as metal fragments in the CT scans, it is moved to the adjacent MRI suite for an MRI scan. Depending on the suspected pathology, the proper sequences are selected. After finishing the imaging procedures, the body is ready for the standard legal examination. Based on the data gathered during medical imaging, the autopsy approach can be planned.

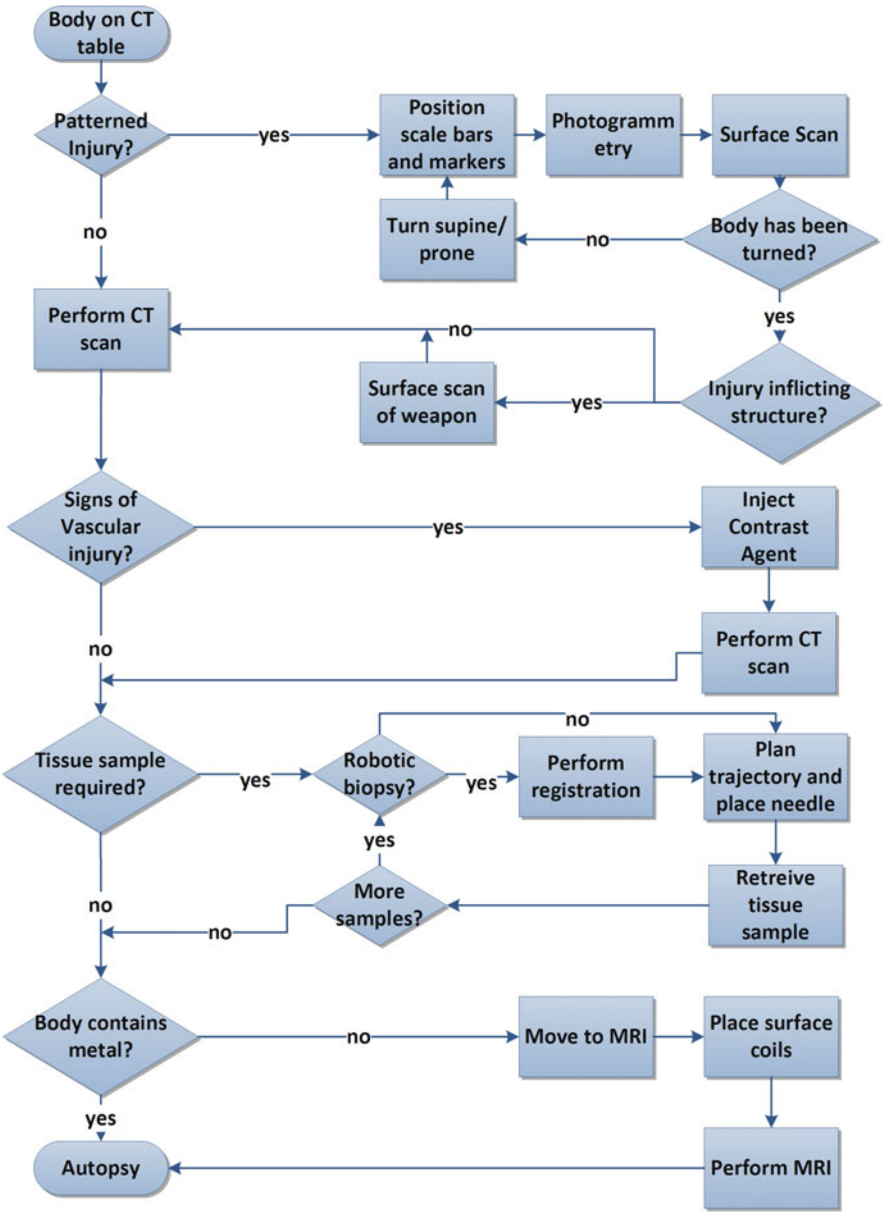

Fig. 9.2.7.1 Workflow of a standard Virtopsy

9.3 Visualisation: The Main Concepts for Storage, Processing and Visualization of Medical Image Data

9.3.1 Data Storage

Modern radiological scanners generate vast amounts of data. To ensure intra-operability between different manufacturers, the DICOM[3] (Digital Imaging and Communication in Medicine) standard was introduced in the early 1990s. The standard not only defines how data is stored, but also the necessary communication protocols. CT and MRI datasets consist of a three-dimensional array of volume pixels (voxels). In CT imaging, each voxel has a size and a Hounsfield value, e.g. an x-ray density. In MRI imaging, the value of a voxel is unitless but otherwise stored in the same format. Surface scanning usually generates three-dimensional polygon meshes. Different standard formats exist for storing polygon meshed, the one most commonly used especially in conjunction with rapid prototyping techniques is STL.

Medical imaging data is stored and analyzed by radiologists using a *Picture Archiving and Communication System* (*PACS*). PACSs communicate with medical imaging hardware using the DICOM standard and provide backup services for data integrity. Additionally, dedicated workstations offer different tools for visualization. The configuration as well as the available functions depend on how it is being used and how it can optimally be integrated into the workflow of an institute.

9.3.2 Imaging in Two Dimensions (2D Imaging)

Standard means of looking at medical imaging volume datasets are transversal, cross-sectional cuts. Since current computer screens only can display up to 256 shades of gray, only a selected segment of the 3070 values of the standard Hounsfield scale can be displayed at a time. This is achieved by applying a technique called *windowing*. In windowing, a range of Hounsfield values is defined and transformed to grayscale values. Higher values are depicted as white, lower values as black. By using different windows, different tissues or pathologies can be visualized. They are named to by the tissue that is seen best, i.e. soft tissue, lung, and bone window (Fig. 9.3.2.1).

Modern workstations allow the user to change the plane of the image (the angle of the cutting plane through the volume of data) in realtime. This allows for views that follow local anatomies rather than transversal cuts. If necessary, curved cuts are possible to follow the course of vessels or generate panoramic dental views, so-called *orthopantomograms* (Fig. 9.3.2.2). For diagnostic purposes, PACSs allow the user to measure distances and surface areas on reconstructed planes.

[3] http://medical.nema.org/

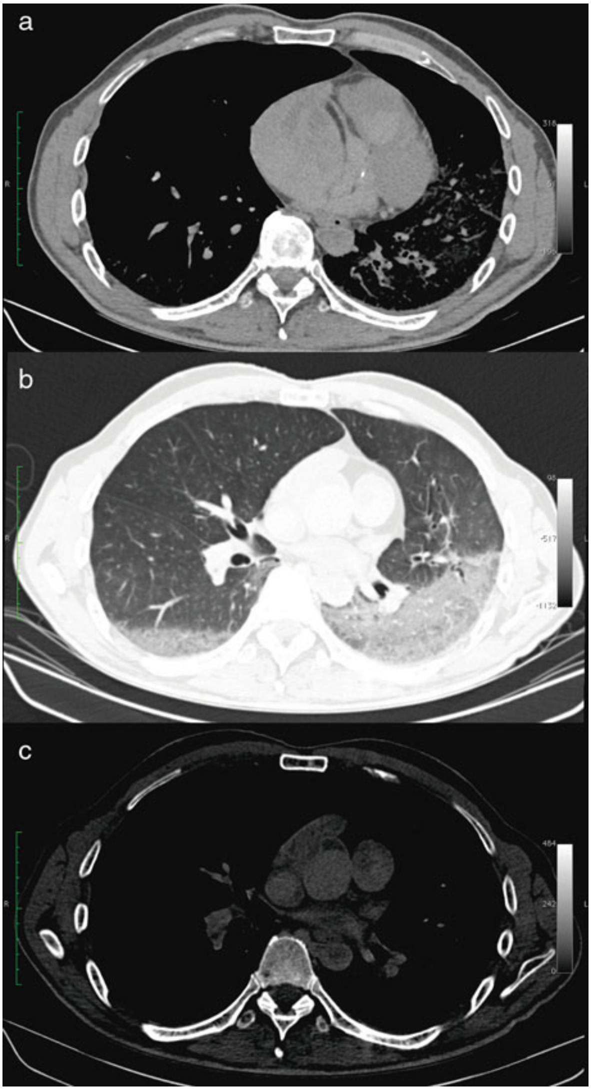

Fig. 9.3.2.1 The same axial cut in a CT dataset with different window levels, giving information about different tissues. (**a**) Soft tissue window. (**b**) Lung window. (**c**) Bone window

9.3.3 Imaging in Three Dimensions (3D Imaging)

Cross sectional imaging is only able to provide two-dimensional views of data that is actually three-dimensional. All PACSs feature a multi planar reformation (MPR) tool, that allows the user to reformat images in the axial, coronal and sagittal image plane. MPR permits localization in three simultaneous planes as well as the exact adjustment of CT exams, for instance to match follow-up exams with a previous study or for the assessment of complex findings (Fig. 9.3.3.1).

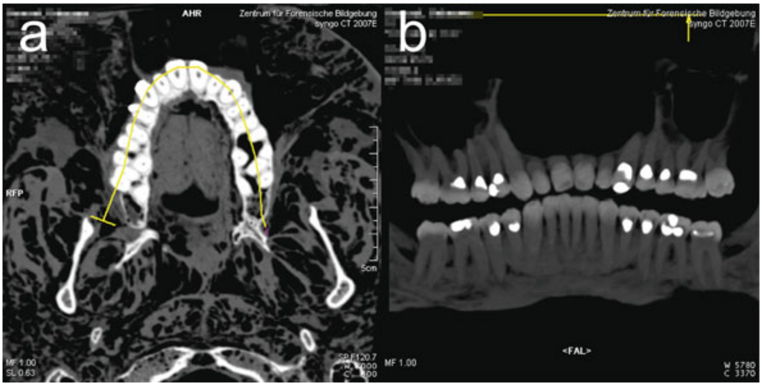

Fig. 9.3.2.2 Dental reconstruction for comparison with ante-mortem images (Leonardo). (**a**) Curve along which the orthopantomogram is calculated. (**b**) MIP orthopantomogram along the path in a

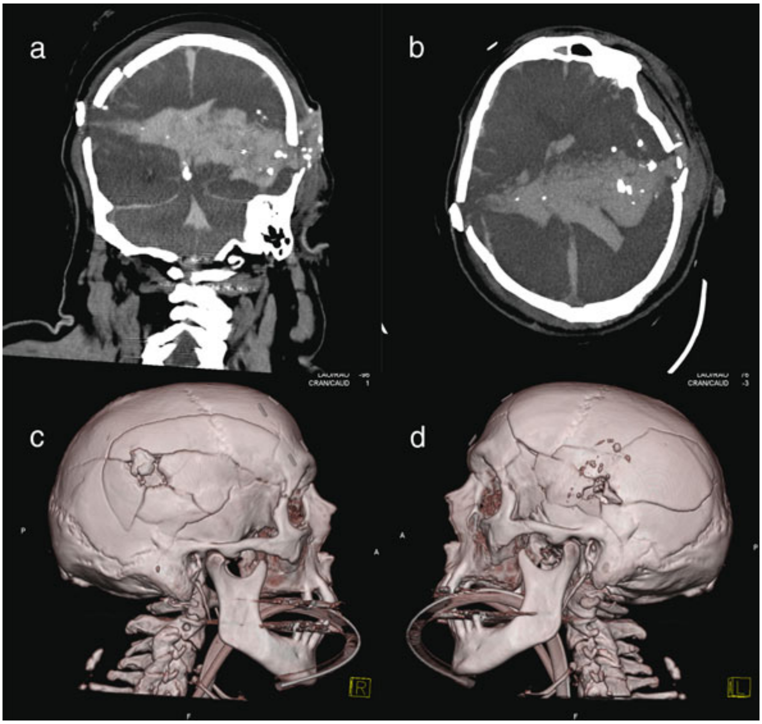

Fig. 9.3.3.1 Gunshot to the head. (**a**) Coronal image (MPR) along the bullet trajectory displaying entry wound (*left*) and exit wound (*right*). (**b**) Axial view of the bullet trajectory. (**c**) Volume reconstruction of the entry wound displaying the bone damage (Leonardo). (**d**) Volume reconstruction of the exit wound (Leonardo)

An other technique to display a dataset as a whole is the so-called volume rendering. Similar to windowing, a transparency and a color is assigned to each voxel, based on its Hounsfield value. The function defining this mapping is called transfer function. Since the x-ray densities of different tissues are known, predefined transfer functions allow the depiction of bone, soft tissue and skin in colour.

Different shaders allow for a better three-dimensional perception of the generated images. Some special shaders are used for specific task. While standard volume rendering techniques take all transpacencies and colors of voxels along a ray into account, Maximum Intensity Projection (MIP) only uses the highest value. This allows for excellent skeletal, angiographic, and metallic detail. A Minimum Intensity Projection on the other hand only uses the lowest Hounsfield value, which best displays gas collections inside the body.

9.3.4 Animation

Unlike medical imaging data, surface scanning produces textured 3D polygon meshes. Since polygon models are easier to manipulate than volume datasets, it allows repositioning of the models and the reconstruction of a sequence of events based on injury patterns and other facts.

For this task, dedicated animation software such as 3D studio MAX (from Autodesk, USA) is used. The polygon models (bones, surface etc.) can be imported directly. A virtual bone system for animation (biped) can be created and adapted to the properties of the polygon model that is to be animated. The biped consists of a set of joints that are linked to each other and have the same range of motion as the corresponding real joint. Bipeds are relatively easy to animate compared to polygon models with thousands or even millions of polygons. The polygon model is now linked to the *biped* (*rigging*) and every motion on the biped is copied to the polygon model (Fig. 9.3.4.1).

For animation, the biped can be put into different postures at different point in times, the animation is then calculated by interpolating between these postures. This technique is called *keyframing*. It is important to note that animation should be used carefully and should only show motions or positions that are based on facts.

There is in the scholarly literature some discussion of how jurors (in jurisdictions with a jury) may be affected by viewing computer animations: this may be facilitating, but unless special care is taken, there is some risk of prejudicial effects (Kassin & Dunn, 1997).[4]

[4] Schafer and Keppens (2007), who were discussing computer animation in the context of computer-assisted teaching in evidence courses, have remarked: "In this animation, two competing theories that both claim to account for the evidence are modelled side by side. According to the prosecution, the evidence found was produced by a cold-blooded killing, according to the defence, it was caused by events more consistent with the assumption of self defence. As we can see from the models, only the defence hypothesis produces the type of evidence that was found, in particular it accounts for the bullet trajectory found in the victim. The user can directly change the

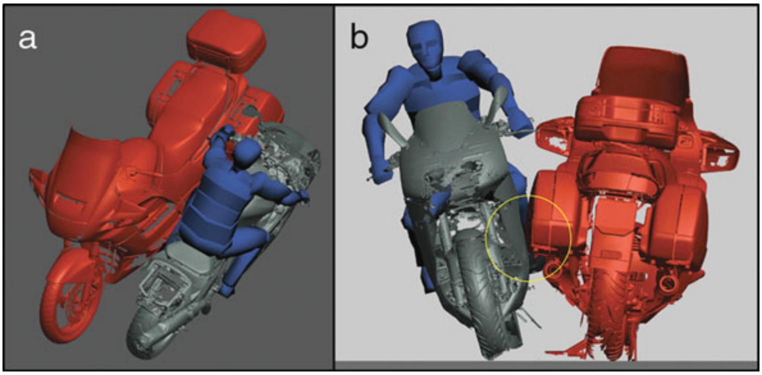

Fig. 9.3.4.1 Biped reconstruction of a traffic accident based on surface scans of the motorcycles. The positions during impact have been reconstructed by combining damages on the vehicle with injury patterns documented by photogrammetry, surface scanning and CT

9.3.5 Segmentation

Volume estimations in medical image datasets are possible with a technique called segmentation. In segmentation, each voxel in a dataset is assigned to a material. This way, each organ, pathology, gas collection, fluid collection or tissue can be assigned to a material. Since the volume of a single voxel is known, the volume of all voxels belonging to a material can be calculated. By combining this information with a known density of the tissue, even the weight of organs can be estimated.

Depending on the modality and the pathology or tissue to segment, automatic, semi-automatic and manual techniques exist. In manual segmentation all voxels of a specific material have to be selected by hand. Semi-automatic methods such as region growing and line wire algorithms assist the user to quickly select similar

---

position of the people involved, the computer calculates how this would have affected the evidence that was created. The scientific knowledge that underlies these models is complex. To calculate the relevant trajectories requires knowledge of geometry and kinetics, to reason about the ability of the accused to shoot from a specific position requires biological, biomechanical and medical knowledge. How much can a hand holding a heavy gun rotate? What would the recoil do to the ligaments? Moreover, it is not contested knowledge, and hence of little interest to the lawyer pleading the case. Nonetheless, the manipulation of the relevant parametric and geometric equations is taken care of by the computer. The user only needs to manipulate the physical objects (victim, gun, accused) to test different theories and explanations. To hide expert knowledge in this way does create problems if these models are used as evidence, in particular if they are used in an adversarial, partisan context. There is also the danger that computing constraints add facts that are either not established, or not established in legally permissible ways (Selbak, 1994; Kassin & Dunn, 1997; Menard, 1993). In our example for instance, the jury may be subconsciously swayed by the facial expressions of the animates, even though they have not been introduced through a witness into the court proceedings. These problems in using computer models in courts are however an advantage when using them for teaching. Without the need for time consuming mathematical preparation, students can be directly exposed to critical scientific thinking and substantive forensic subjects."

structures. Fully automatic methods are usually organ specific, sensitive to artifacts and contrast changes inside the dataset and fail to deliver data in decomposed bodies or in cases with significant pathologies or extensive damages.

Some software packages such as animation software require polygon meshes and cannot be use with on volume datasets directly. For visualization involving animation, the selected materials can be converted into a 3D polygon mesh by using the marching cubes algorithm. A combination of volume and polygon based rendering can then be used to demonstrate the relevant pathologies.

9.3.6 Image Fusion

Different modalities are used in Virtopsy. Each modality has a specific field of application with respect to different pathologies. In order to get a complete picture and correlate injuries visible in different modalities, it may be necessary to fuse different datasets and combine their information (Thali, Braun, Wirth, Vock, & Dirnhofer, 2003).

Since all datasets have their own independent local coordinate system, a co-registration has to be performed. The standard means of registration is a paired-point registration, where a set of markers is visible in both modalities. The markers are selected in both modalities and the transformation is calculated by minimizing the distance error between the paired point. If the surfaces are similar enough, surface matching can be performed instead.

9.3.7 Rapid Prototyping

Another application of segmentation is rapid prototyping. *Rapid prototyping* is actually a broader concept from *software engineering* – and it is often adopted while developing in a principled manner software systems in general – but in the present context it refers to a group of techniques that quickly generate physical models based on *Computer Aided Design* (*CAD*) data in small quantities.

State of the art methods for rapid prototyping are *stereolithography* and *3D printing*. Both techniques build up the physical model layer by layer. While stereolithography uses a liquid resin, which is selectively hardened by ultraviolet (UV) light, 3D printing spreads layers of powder onto a table and selectively binds them with colored glue. Unlike milling techniques, these techniques allow for the creation of occluded structures (internal cavities). 3D printing additionally delivers fully colored models.

Rapid prototyping cannot work with volume datasets, requiring polygon meshes and therefore will only work in conjunction with data that is prepared using segmentation techniques. Rapid prototyping techniques can be used for educational purposes or to present medical findings in a way, that is easily understood by medical laypersons, which is a common scenario in forensic investigations (Dolz, Cina, & Smith, 2000).

9.3.8 Post-mortem vs. Ante-mortem Imaging

Even though medical imaging techniques used in Virtopsy are the same as methods used in clinical medicine, interpretation of post-mortem image data sets has some differences. Changes common in deceased individuals can be mistaken for pathologies. This includes, but is not limited to: collections of gas due to decomposition, clotted blood and internal lividity. MRI scans change their appearance, if the body temperature is too low. Therefore it is advisable that post-mortem studies be evaluated by radiologists who are experienced in post-mortem imaging.

9.3.9 Medical Image Data for Radiologists and Pathologists

Traditionally, radiologists look at volume datasets using transverse cuts either through the body, or through single organs. The possibility to measure distances and surfaces is of additional diagnostic value. The slice stack is browsed through several times with different window levels, in order to view each tissue with the most appropriate contrast.

If necessary, for instance in cases of train suicides, a volume rendering can help to quickly perform an inventory of all body parts. For special purposes such as dental identification, methods such as MIP or VRT are used. Since the use of post-mortem CT angiography alters the liquid levels in vessels, volume measurements performed during autopsy are not reliable after such an intervention. In those cases, segmentation techniques are used instead.

MIP stands for *Maximum Intensity Projection*, whereas *VRT* stands for *Volume Rendering Techniques.* An explanation for both follows.

- *Volume rendering* displays the dataset as a whole, thereby providing a better perception of the three-dimensional structure of a CT dataset. So-called transfer functions are applied to the Hounsfield values[5] to derive voxel properties,

[5] Hounsfield units are a measure of density. For example Aamodt et al. stated (1999, p. 143): "Our aim was to assess in Hounsfield units (HU) the CT density of the inner cortical surface of the proximal femur after this bone had been removed. One HU is defined as a number on a density scale in which the X-ray absorption of water has been assigned the value of zero and the air the value of –1000."

http://en.wikipedia.org/wiki/Hounsfield_scale provides this definition: "The *Hounsfield scale*, named after Sir Godfrey Newbold Hounsfield, is a quantitative scale for describing radiodensity. [. . .] The Hounsfield unit (HU) scale is a linear transformation of the original linear attenuation coefficient measurement into one in which the radiodensity of distilled water at standard pressure and temperature (STP) is defined as zero Hounsfield units (HU), while the radiodensity of air at STP is defined as –1000 HU. For a material X with linear attenuation coefficient μ_X, the corresponding HU value is therefore given by

$$HU = \frac{\mu_X - \mu_{\text{water}}}{\mu_{\text{water}} - \mu_{\text{air}}} \times 1000$$

such as color and transparency. (A *voxel* is the volume unit, just as a *pixel* is a unit in the plane, in two-dimensional images.)

- *Maximum intensity projection* (*MIP*) is a way of presenting CT datasets by only displaying the voxel with the highest value along a projection ray. Information about the three-dimensional structure is lost, but it allows comparing CT datasets to orthopantomograms for dental identification.

Orthopantomograms, also called *orthopantograms*, *OPG*, or *panorex*, are not known to the non-specialist by that name, but the thing they name is familiar to dentists' patients, as they are a panoramic scanning *dental X-ray* of the upper and lower jaws, showing in two dimensions a half-circle from ear to ear. One advantage of such *panoramic* images is their coverage is broad, capturing both facial bones and the teeth, and another advantage is that also patients find the image is easy to understand. Such images can even be made in patients who cannot open their mouth, as the image is shot by introducing in the mouth a flat plastic spatula: dentists ask patients to bite on it, and the process takes about one minute. It is not only on living individuals that such dental X-rays can be taken, and they are useful indeed for identifying bodies. *Dental radiology* uses either *film technology* (which requires a chemical development process, and with the film on either a flat cassette, or a rotating cylinder), or *digital technology.* The first dental panoramic digital systems were designed in 1985–1991. In 1995, Signet, a French firm, introduced DXIS, the first dental digital panoramic X-rays system available on the market. In 1997, Siemens followed, with SIDEXIS. Since then, many manufacturers have been offering their own panoramic digital systems for dental X-rays.[6]

---

where μ_{water} and μ_{air} are the linear attenuation coefficients of water and air, respectively. Thus, a change of one Hounsfield unit (HU) represents a change of 0.1% of the attenuation coefficient of water since the attenuation coefficient of air is nearly zero. It is the definition for CT scanners that are calibrated with reference to water. *Rationale*[:] The above standards were chosen as they are universally available references and suited to the key application for which computed axial tomography was developed: imaging the internal anatomy of living creatures based on organized water structures and mostly living in air, *e.g.* humans. [...] The Hounsfield scale applies to medical grade CT scans but not to cone beam computed tomography (CBCT) scans."

The HU of air is –1000; the HU of fat is –120; the HU of water is 0; the HU of blood is +30 to +45; the HU of muscle is +40; the HU for contrast is +130; the Hu of bone is +400 or more (ibid.). "A practical application of this is in evaluation of tumors, where, for example, an adrenal tumor with a radiodensity of less than 10 HU is rather fatty in composition and almost certainly a benign adrenal adenoma" (ibid.). Something about the history of the technology: "CT machines were the first imaging devices for detailed visualization of the internal three-dimensional anatomy of living creatures, initially only as tomographic reconstructions of slice views or sections. Since the early 1990s, with advances in computer technology and scanners using spiral CT technology, internal three-dimensional anatomy is viewable by three-dimensional software reconstructions, from multiple perspectives, on computer monitors. By comparison, conventional X-ray images are two-dimensional projections of the true three-dimensional anatomy, i.e. radiodensity shadows. It was established by Sir Godfrey Newbold Hounsfield, one of the principal engineers and developers of computed axial tomography (CAT, or CT scans)." (ibid.).

[6] http://en.wikipedia.org/wiki/Orthopantomogram states the following concerning the equipment: "Dental panoramic radiography equipment consists of a horizontal rotating arm which holds an

9.3.10 Medical Image Data for Medical Laypersons

If radiological data has to be presented to non-medical professionals, grayscale transverse cuts as used by radiologists are insufficient, since interpretation of these data requires experience and training. This is especially important in forensics, since

---

X-ray source and a moving film mechanism (carrying a film) arranged at opposed extremities. The patient's skull sits between the X-ray generator and the film. The X-ray source is collimated toward the film, to give a beam shaped as a vertical blade having a width of 4–7 mm when arriving on the film, after crossing the patient's skull. Also the height of that beam covers the mandibles and the maxilla regions. The arm moves and its movement may be described as a rotation around an instant center which shifts on a dedicated trajectory. The manufacturers propose different solutions for moving the arm, trying to maintain constant distance between the teeth to the film and generator. Also those moving solutions try to project the teeth arch as orthogonally as possible. It is impossible to select an ideal movement as the anatomy varies very much from person to person. Finally a compromise is selected by each manufacturer and results in magnification factors which vary strongly along the film (15–30%). The patient positioning is very critical in regard to both sharpness and distortions."

The image is formed as follows (ibid.): "Normally, the person bites on a plastic spatula so that all the teeth, especially the crowns, can be viewed individually. The whole orthopantomogram process takes about one minute. The patient's actual radiation exposure time varies between 8 and 22 seconds for the machine's excursion around the skull. The collimation of the machine means that, while rotating, the X-rays project only a limited portion of the anatomy onto the film at any given instant but, as the rotation progresses around the skull, a composite picture of the maxillo-facial block is created. While the arm rotates, the film moves in a such way that the projected partial skull image (limited by the beam section) scrolls over it and exposes it entirely. Not all of the overlapping individual images projected on the film have the same magnification because the beam is divergent and the images have differing focus points. Also not all the element images move with the same velocity on the target film as some of them are more distant from and others closer to the instant rotation center. The velocity of the film is controlled in such fashion to fit exactly the velocity of projection of the anatomical elements of the dental arch side which is closest to the film. Therefore they are recorded sharply while the elements in different places are recorded blurred as they scroll at different velocity."

There is image distortion (ibid.): "The dental panoramic image suffers from important distortions because a vertical zoom and a horizontal zoom both vary differently along the image. The vertical and horizontal zooms are determined by the relative position of the recorded element versus film and generator. Features closer to the generator receive more vertical zoom. The horizontal zoom is also dependent on the relative position of the element to the focal path. Features inside the focal path arch receive more horizontal zoom and are blurred; features outside receive less horizontal zoom and are blurred. The result is an image showing sharply the section along the mandible arch, and blurred elsewhere. For example, the more radio-opaque anatomical region, the cervical vertebrae (neck), shows as a wide and blurred vertical pillar overlapping the front teeth. The path where the anatomical elements are recorded sharply is called 'focal path'."

Digital dental radiology, using electronic sensors and computers, offers advantages (ibid.): "One of the principal advantages compared to film based systems is the much greater exposure latitude. This means many fewer repeated scans, which reduces costs and also reduces patient exposure to radiation. Lost X-rays can also be reprinted if the digital file is saved. Other significant advantages include instantly viewable images, the ability to enhance images, the ability to email images to practitioners and clients (without needing to digitize them first), easy and reliable document handling, reduced X-ray exposure, that no darkroom is required, and that no chemicals are used."

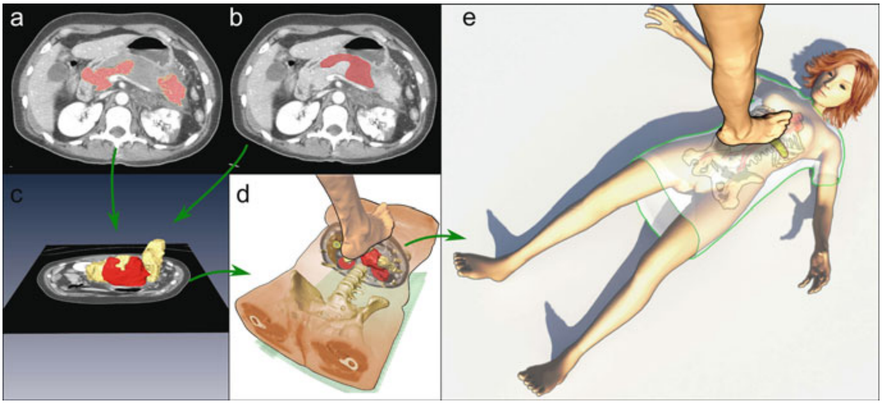

Fig. 9.3.10.1 Visualizing a pancreatic rupture after kick to the chest. (**a**) Segmented pancreas. (**b**) Segmented extravasated blood. (**c**) Polygon model of the segmented pancreas and blood. (**d**) Combination of volume rendering and polygon models. Transparent soft tissue is displayed by volume rendering. Bone, pancreas and blood are displayed as polygon models. (**e**) Final result of the reconstruction that can be put into a virtual crime scene, based on the physical evidence found

lawyers, judges and the jury are not accustomed to this kind of data. A rather simple way of depicting axial cuts is by coloring and labeling different organs. Additionally, a volume rendering showing the plane can help with better orientation.

3D imaging is especially useful for presenting information to an audience of medical laypersons, since it is self-explanatory in most cases. While bone fractures can be displayed directly using volume rendering techniques, some injuries require a combination of segmentation, polygon rendering and volume rendering. Additionally, 3D images can be combined with additional information such as force vectors, position of weapons or attackers during attack, if this is supported by evidence (Fig. 9.3.10.1).

9.4 Virtopsy and the Swiss Justice System

9.4.1 Advantages of Virtopsy in Court

Court members are normally laypersons with respect to forensic medical issues. For them, pictures of conventional autopsy can be distasteful and difficult to interpret. A real autopsy is, honestly, a rather grim process. On the other hand, Virtopsy pictures allow for a more or less abstract look at the inside of a human being. Therefore, Virtopsy pictures are routinely less distasteful and/or disturbing for court members. These types of pictures are more easily understandable, are normally less error prone (e.g. left side / right side confusion), enable three-dimensional color coded reconstructions and provide excellent visualization of given anatomy.

Furthermore, three-dimensional images can easily be shown in court rooms and interactively discussed with court members and other relatives of the deceased. Since Virtopsy data can be stored, with no loss of quality, they can be reused years after they have been made in case additional questions arise, possibly averting the need for exhumation. Virtopsy methods in general are non-destructive, which obviates the possibility of destroying evidence during the procedure.

9.4.2 Virtopsy in the Current Legal System and Practice of Switzerland

Notwithstanding the foregoing, and in particular, notwithstanding these advantages in dealing with criminal cases, Virtopsy is not yet anchored within the present Swiss legal system, meaning the Virtopsy technique is actually not specifically mentioned, in either acts of law or decrees. Moreover, prevailing case law and legal doctrine theory has yet to deal with this forward looking approach in forensic investigation.

The Virtopsy technique is based on research, ongoing for nearly a decade; however it is not yet part of the standard operating procedures of the Swiss Academy of Legal Medicine, which develops the guidelines that define due diligence in the field. On the other hand, the technique is part of the training program for future forensic pathologists at several Swiss universities. These seemingly disparate facts indicate that Virtopsy is not yet an element of what would be considered best practice in Switzerland.

However, the technology is used within certain areas of Switzerland, where the technique is implemented and well established (i.e., the Institute of Forensic Medicine at the University of Bern and its catchment area: the cantons of Bern, Aargau and Solothurn, and in the Canton Wallis, the district Oberwallis). Members of the legal practice in Bern, and in more and more in other cantons such as Lausanne and Zurich, take advantage of the new technique and apply it in conjunction with expert testimony as well evidence that helps to establish the burden of proof in criminal cases.

9.4.3 Criminal Procedure in Switzerland: The Legal Basis for Virtopsy Imaging Methods?

9.4.3.1 Background

Since January 1, 2011 a new, national Swiss Code of Criminal Procedure (SCCP) has been in effect. In Switzerland, the penal authorities include the following: in criminal prosecution the police, the office of the District Attorney, misdemeanor penal authorities, as well as several Courts such as trial court, the appeal board and appeal court at the cantonal level, and the Federal Supreme Court of Switzerland at the national level. Article 14 of the SCCP allows each canton to organize its own trial courts (such as circuit court, district court, and county court, etc.).

Article 328 of the SCCP,[7] which deals with procedure at the lowest court level, contains no specific regulation regarding the conduct of jury trails, which are therefore not yet instituted in Switzerland. Hence, professional judges preside over the courtroom in Switzerland.

9.4.3.2 Legal Basis for Virtopsy in Switzerland

Virtopsy is primarily used for identification of the deceased and for post-mortem investigations of extraordinary deaths (which include offenses, suicides, accidents and unclear deaths). The main Article in SCCP is Article 253, section 3 of which prescribes: "Otherwise, if there is a suspicion of criminal activity, or the identification of a body is in question, the district attorney may take possession of the body and direct further investigations, at times including an autopsy".[8] At this point an interpretation of the law is indispensable, according to the relevant rules of interpretation (grammatical, historical, systematical and teleological interpretation element). Under these rules further investigations cover also medical imaging method like a CT or MRI and other Virtopsy methods. This is the legal basis for the application of Virtopsy tools in criminal prosecution in cases of death.

On the other hand, imaging methods can also be used to investigate injuries of living persons (victims of crime or defendants), identification or cases of drug smuggling.. Articles 249 to 252 of the SCCP regulate the search and examination of living people. Articles 249, 250 concern the examination of the surface and therefore includes the use 3D surface scanning. Articles 251, 252 concern examination of the inside of the body, and are therefore relevant to CT and MRI examinations.[9]

These Articles of the SCCP constitute the basis to perform examinations with Virtopsy and imaging methods in Switzerland. We should add that Article 197 Section 1, subparagraph c of the SCCP implies that a compulsory examination like those named for cases of either (extraordinary) death or of living people (victims of a crime or defendants), have to be the "mildest method" possible. The non- or minimally-invasive methods of Virtopsy better satisfy this regulation when compared to full-invasive autopsy.

9.4.3.3 Evidence Law in Switzerland

In general, the key article of law relevant to Virtopsy in Swiss Evidence Law is Article 139 of the SCCP. All means of evidence that science and experience have shown to be valid for discovering the truth are to be utilized in an investigation. Virtopsy and its imaging methods are such means of evidence; especially because of the fact that imaging methods are non- or minimally-invasive and hence better

---

[7] See Niklaus Schmid's (2009) *Handbuch des Schweizerischen Strafprozessrechts*, N 380.

[8] Article 253 Section 3 Swiss Code of Criminal Procedure (SCCP).

[9] Articles 249–252 Swiss Code of Criminal Procedure (SCCP).

preserve body integrity and human dignity than the classical examinations such as invasive autopsy.

Imaging methods such as CT, MRI or surface scanning are scientifically accepted, in both medicine and surveying. It is the choice of the expert to decide which methods or examinations are necessary to provide an expert opinion.[10] In our opinion, the forensic expert opinion of the 21st century should include all reasonable and available means of evaluation, including medical imaging methods. However, Virtopsy methods do not meet the criteria for exclusion of evidence under Article 140 SCCP.[11]

According to Article 76 Section 4 SCCP the statements of experts can be recorded using technical aids such as images. Hence the use of images is explicitly approved by legislation for use court.[12]

In Switzerland the prosecuting authorities bear the burden of proof. The party of the proceedings, hence the prosecuting attorney as well as the defense can file requests to present evidence. The defending attorney is only bound to the interests of his client. He has the same rights as the defendant himself. The defense can collect its own evidence. Therefore it would be possible for the defending attorney to ask for expert testimony, which might Virtopsy methods.

Additionally, hospital CT and MRI can be used for forensic purposes. There is no ranking of evidence, but a so-called free consideration of evidence by the judge. All means of evidence are basically considered equal, although some evidence seems to be especially trustworthy like evidence produced by electronic equipment. The conviction of the judge is not based on the external but interior authority of a mean of evidence. Free consideration of evidence by the judge is limited, however and may be dependant on expert testimony.

Experts assist the penal authority by imparting their specialist knowledge, as relevant to the case at hand. Experts must deliver results and opinions based on a contentious and state of the art application of the scientific method.[13] The expert is the assistant of the penal authority (prosecuting attorney and court) in his field of expertise, rather like *amicus curiae* in Common law Countries. She or he does not make legal judgements or comments about the evidence. The experts have to possess special knowledge and skills in their respective field of expertise.

A legal inspection (a.k.a the external examination) of the body and the autopsy are performed by forensic experts or by an institute of forensic medicine.[14] During a Virtopsy a radiology expert does a reading of the CT or MRI images and surveying engineers perform surface scans. It is possible therefore for several experts to be employed in the same trial.

---

[10] Schmid Niklaus, N 944 f.

[11] Article 140 Swiss Code of Criminal Procedure.

[12] Article 76 Section 4 Swiss Code of Criminal Procedure (SCCP).

[13] Schmid Niklaus, N 929 f.

[14] Article 253 Section 3 Swiss Code of Criminal Procedure (SCCP).

In Switzerland there is no standing directory of court experts. However according to Article 183 Section 2 SCCP, the Swiss Federation or the cantons can employ permanent or official experts for some special fields, (e.g. the forensic, radiology, and engineering experts of the Institute of Forensic Medicine of the University of Bern). Furthermore, it is mandatory that experts are completely independent and impartial.[15] Both prosecuting authorities and defendants have the opportunity to comment on the qualifications of the expert and the content of the expert report in advance.[16] Hence, there is the possibility of an objection for both sides according to Article 393 SCCP.[17]

The impartial and independent, professional judge has to follow the rule of consideration of evidence and may not give more weight to the visually impressive, intuitive and exact nature of 3D-pictures of the Virtopsy. But in other countries, particularly where juries are involved, the impressive 3D renderings may have considerable sway.

According to Article 189 SCCP[18] if an expert opinion is unconvincing, imprecise, contrary to accepted expectations, or incomplete – in short, if there is any doubt regarding the correctness of the expert opinion – the judge can order a second opinion or an clarification from the first expert opinion. In such cases, Virtopsy has the advantage of the digital nature of the data, which allows for submission anywhere in the world to obtain second expert opinions.

To summarize, the Virtopsy and its imaging methods can be principally used as evidence by either the prosecution or the defense. The professional judge can also request viewing. The images must be annotated by expert commentary by an expert and must be included in the report in an "image folder". The image folder augments classical examination methods such as autopsy in court.

[15] Schmid Niklaus, N 936.
[16] Schmid Niklaus, N 937 f.
[17] Schmid Niklaus, N 940 f.
[18] SCHMID, N 951 f.