Virtopsy®

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Photography, X-rays, Computed Tomography

Using photography [1] and taking plain X-rays are both techniques that were adopted by forensic scientists or forensic pathologists in a flash, as it appears.

As far as *plain X-rays* go, first tests by the German physicist Wilhelm Röntgen were done around November 1885. Not much later, on December 25^{th} 1895 in Montréal, Canada, a male victim suffered a firearm injury to the leg [2]. Only 3 days later, the first scientific article was submitted by Wilhelm Röntgen (then in Würzburg, Germany) as a conference contribution – which immediately made headlines. That conference was the third meeting of the Physical-Medical Society in Würzburg, Germany. There, he talked about "a new kind of rays" on January 23rd 1896 [3]. With the goal to show the surgeon that was to remove the bullet of the aforementioned Canadian victim, a plain X-ray was taken on Feb 7^{th}th 1896 in Montréal, Canada. The patient was sent home ten days later. A court trial was held later, and the radiographs were presented as evidence there. Never has a new scientific or technological breakthrough been so quickly, internationally and universally adopted by the medical and scientific community [4, 5].

Compared to this bush fire type adoption into forensic science, it is surprising to realize that first adopters used CT (computed tomography) already in 1973 [6], but remained largely unused throughout forensic sciences and medicine. Some scientific papers described methods as we use them in modern Virtopsy® such as angiographic methods [7], CT scanning as such [8, 9], photogrammetry or 3D surface documentation [10] and MRI (magnetic resonance imaging)[11]. However, by 1998 – 25 years later – not one forensic medicine institute had added post mortem CT scanning or other 3D scanning methods to their everyday work flow.

Immediate adoption of a new technique by the whole wide world is not always the instantaneous result. It has been brought about by incentives ever now and then though - such as the myoelectric prosthetic arm, whose wider adoption was somewhat forced upon the Western Bloc by their nemesis, the Russians. At the time, the technology to build myoelectric arms appeared to have been available, but no one seemed to bother with building products that amputees could use (e.g., [12, 13]). In the middle of the cold war, to the embarrassment of Western countries [14], out of the blue (or so it appeared), the Russians demonstrated a ready-to-use

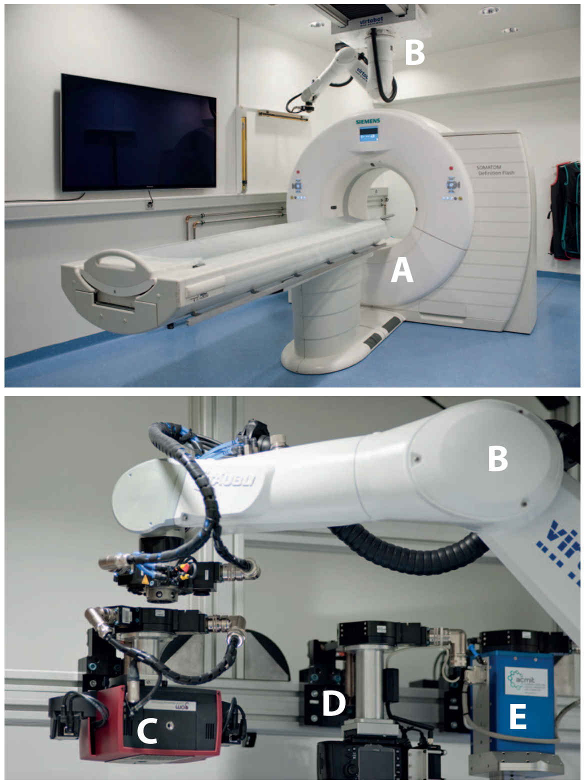

Figure 1: Virtopsy®system. The CT scanner (A) and its table are located within the reach of a ceiling mounted robot arm (B). The arm carries various tools which are picked up automatically, such as a 3D surface scanner (C), a photographic mirror reflex camera (D) and a system to target and place biopsy needles (E).

arm dubbed the "Russian Arm" [15]. After that, the Western bloc countries, to their embarrassment, had to send delegations to Russia to "learn about it" [16]. Interestingly, the wider adoption of post mortem forensic imaging was preceded by a similar incentive: one institute charged ahead and just did it.

Virtopsy®

The Virtopsy®research was in part initiated by a high-profile case (see Fig. B1.1.3, p. 53 in [17]). First body scans were started by our group in 1999 using project names such as "digital autopsy" or "scalpel-free autopsy". With that, the Virtopsy®-project[1] was born [18]. This project was not the first attempt to use CT or MRI post mortem scanning worldwide (see references above), but it was undoubtedly the first to incorporate a broad range of technologies such as CT, MRI, biopsies (see Fig. 1 for an overview of the Virtopsy®system also containing a Virtobot®), 3D surface scanning (see Fig. 2 for an example of surface data evaluation and injury matching) while also examining as many cases as possible over an extended period of time and in a systematic manner. A considerable number of traditional forensic pathologists expressed a "dislike" for these new methods, but at the very same time, this immediately was news all over the globe.

The targeted activity of the Virtopsy®research group around Richard Dirnhofer was widely communicated in conferences after 1999. Systematic approach and broad scope was unprecedented (e.g., gunshot focused research [19], sharp force trauma

[1] www.virtopsy.com

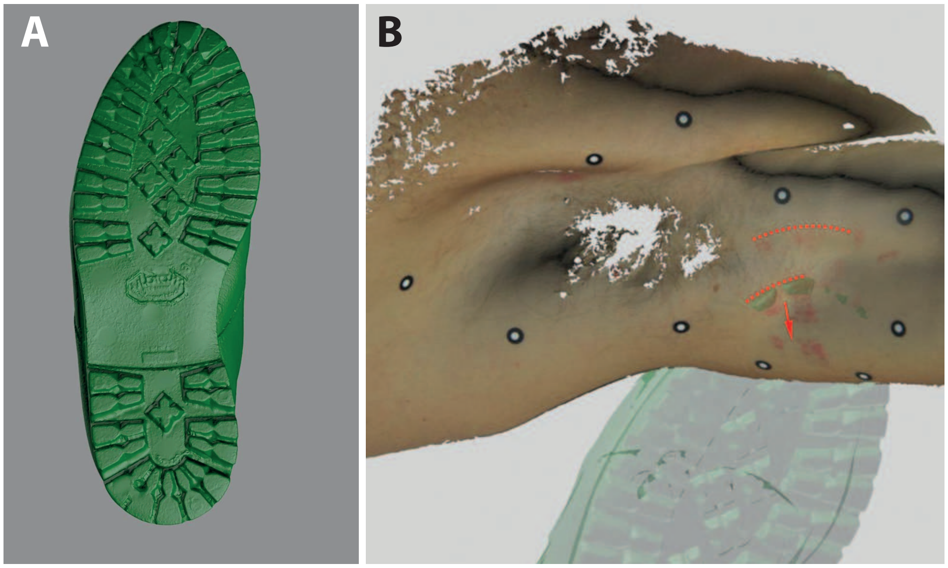

Figure 2: Footprint analysis: Middle-aged male was attacked. While lying on the ground, the perpetrators kicked him in the head and the trunk. One of the shoes left an imprint in the arm pit. This injury as well as the shoe were both documented using 3D photogrammetry and surface scanning. 3-dimensional reconstruction permits direct matching of the injury and injury-causing instrument.

[20, 21, 22], heat and strangulation [23], post mortem interval estimation [24, 25], skull and brain injury [26], heart focused research [27, 28, 29], 3D surface pattern matching [30, 31]). Subsequently, results were made available also in compiled form [32, 33, 17].

Virtopsy®subsequently developed into a multi-tool documentation and analysis research project [17], combining 3D body surface imaging methods with merged CT/ and MRI-data and 3D shape analysis [34, 35, 36, 37, 38, 39], the application of multidetector or multislice [40] CT and MRI found continued interest[41, 42, 43, 44, 45, 46] also for problems specific to clinical forensic medicine [47, 48], then for high-resolution micro-CT [49, 50] and micro-MRI (MR microscopy) [51], magnetic resonance spectroscopy (time-of-death determinations) [52, 53, 54], image-guided percutaneous biopsy [55, 56, 57, 58, 59], postmortem angiography [60, 61, 62, 63, 64, 65, 66], post mortem identification [67, 68], postmortem ventilation [69, 70], and non-invasive tool and data display control such as the integration of a Kinect camera [71, 72] or 3D printing and rapid prototyping [73]. Added value for the conventional autopsy results from improved planning and better diagnostics. Some concise advantages are the identification and incorporation of bone bruises into accident reconstructions [45]), the identification of gas (relevant in diving related deaths [74, 75, 76]), the ability to identify pathology in decaying tissue (that can be difficult if not impossible to handle manually at dissection [77, 78]), the ability to extract and use information related to (chemical) material composition [79, 80], documentation of medical installations [81] and exploitation of digital data for reconstructive purposes [34, 35, 82, 39]. Furthermore, advances in usage of reconstructive aspects of 3D CT reconstructions have lead to routine integration of forensic aspects into clinical forensic medicine (Fig. 3). In the last 15 years, there have been numerous publications on forensic imaging [83]. The significant technological step in forensic medicine can be described as the advancement from the "forensic camera obscura" to "Star Trek-like Virtopsy®and Virtobot®technologies" [17]. However, the core aim of the Virtopsy®project is not to eliminate the classical approaches, but to implement imaging techniques in forensic medicine that are at the level of the current technology.

Figure 3: In this case, an initial forensic question was what type of violence had caused this man's head injuries leading to a significant nose bleed and a frontal epidural hematoma. The man had reported to having fallen from his bicycle. He bled so much that he was admitted to a hospital where he was sedated, intubated and ventilated; so far he survived the injury. Clinical radiologists did report frontal, mid face and mandibular fractures, but no details as to their shape, distribution or relative size. Forensic assessment (see 3D reconstruction of clinical skull CT data) yielded a wide-spread fracture pattern spanning forehead, midface and mandible, containing a radial impression fracture of the frontal bone, with emerging burst lines towards the back of the head, across the mid face and with a partly comminuted fracture of the mandible. With this, the injury is consistent with massive blunt force as inflicted by a flat structure such as riding a bicycle straight into a bridge pillar that he must have overlooked.

Current status and outlook

Currently, there are a few centers that offer 3D model testing (such as the Institute of Forensic Medicine in Bern, Switzerland [84, 84, 85]) and 3D scanning (centers in Bern and Zürich, Switzerland) [36]). Post mortem imaging following the Virtopsy®approach is increasingly being employed around the world. This was apparent already a few years ago [86] while in the meantime, major implementations seem to be underway at least in the United Kingdom of Great Britain as well as the United States of America [87].

In forensic pathology, the following work flow emerges as standard: 3D surface scanning to document body surface and injuries in 3D and CT scanning to document any bone injuries and gross pathology.

The forensic imaging approach has the following potential:

- Recorded data are observer-independent, archived for later retrieval and can be reviewed by others or subjected to new analytical techniques and possibilities for teleradiopathology are opened (second opinion).
- Material analysis is possible or approximated [80].
- Scanning is nondestructive and does not tamper with the forensic evidence.

- Data provide a 1:1 match to the body and correct 3D geometry in xyz-axes or spatial documentation, which can be used as the basis of 3D scientific reconstruction.
- The approach provides an alternative or additional examination that "sees" different aspects of the body, as CT "sees" with X-rays and MRI "sees" chemical distributions [88].
- Difficult-to-examine body areas can be examined (e.g., face, neck, spine, pelvis).
- The technique could be considered in cultures and situations where autopsy is not tolerated by religion or is rejected by family members (e.g., psychological reasons) [89, 90].
- Bodies contaminated by infection, toxic substances, radionuclides, or other bio-hazards (i.e., bioterrorism) can be subjected to touch-free examination (more detailed requirements see e.g. [91]).
- 2D and 3D post-processing are provided for visualization of the findings, which may be particularly relevant for people not present during the examination.
- A case's presentation in court may be understood better, easier and more matter-of-factually [92].
- A new strategy option is introduced, specifically, examining a case step-wise. This is achieved by first doing an external inspection, then possibly a CT scan, then reading the data, then possibly an MRI, again evaluating the data, and ultimately deciding whether to do or not do to an autopsy. Thus, cases can be examined in a way that optimizes quality and cost.

The forensic imaging approach (when applied alone) also has the following disadvantages:

- CT scanners have limited soft tissue contrast.
- Organ colors cannot be visualized (so that, e.g., inflammation, tumor, scars, etc. can be hard to discriminate).

It is necessary for those interested in the future of forensic imaging to cooperate on an international basis at a high level, exchanging and sharing research results and acquired experience. There is a need for the education and teaching of highly trained professionals, which requires both financial support and enthusiasm. In light of global terrorism, it might be possible for the forensic field to acquire grant-based financing. Government Institutions and Homeland Security and national research grants are already starting to consider funding research about this topic. As such, financial support seems more possible than in previous years. For that purpose, the International Society of Forensic Radiology and Imaging[2] was founded in 2011. Additionally, in 2012, the Journal of Forensic Radiology and Imaging[3] was born. A new "Forensic Radiology" subdiscipline thus has opened up, bridging the worlds of Forensics and Radiology.

Because the Virtopsy®multi-tool approach will create a process of change in forensic medicine over the subsequent decades, teaching will be an important and core topic over the next few years. CSI television series have resulted in an increased interest in the forensic sciences [93, 94]. With the adoption of new imaging techniques, forensic sciences have indeed opened up a new area of research and a new area for service options.

[2] www.isfri.org
[3] www.jofri.net

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