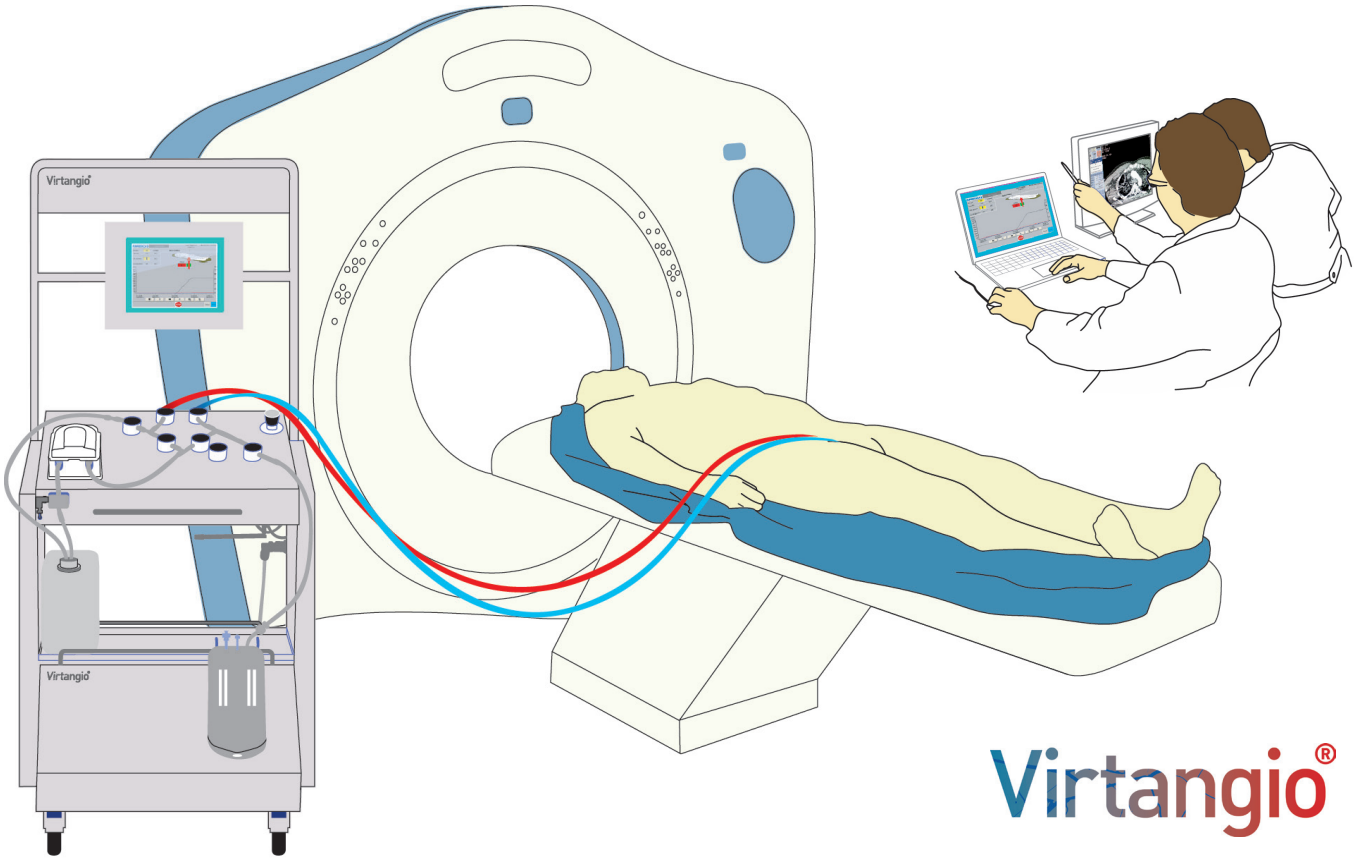
Postmortem imaging
CT, PMCTA, MPMCTA, MRI

State of the art, review and outlook

em. Prof. Richard Dirnhofer



Virtangio®

Glossary

Virtopsy – virtual autopsy

This umbrella term describes a forensic medicine technique developed with the aim of replacing a large proportion of forensic autopsies (also known as postmortem examinations) with a minimally invasive procedure.

The impetus for this was an exponential technological advance in medical imaging, especially with regard to CT, MRI, PMCTA and MPMCTA. The term "I-autopsy", derived from "imaging autopsy", is also in common use in Japan.

Last but by no means least, the umbrella term for the paradigm shift in the medical and scientific field of autopsies (postmortem examinations) has even found its way into the vocabulary of *Time* magazine.

Postmortem imaging

Postmortem imaging is when medical imaging technology is used to examine the deceased persons, not only in a forensic capacity, but also in the fields of anatomy and pathology.

Computed tomography (CT)

An imaging technique for visualising body tissue using x-rays. Just as with conventional radiography, contrasts develop based on the varying extent to which different tissues and materials absorb the x-rays. CT allows excellent visualisation of the skeleton and lungs as well as foreign objects.

Magnetic resonance imaging (MRI)

Visualisation of human tissues by means of strong magnetic fields and radio waves, but without ionising radiation. This examination takes longer than the CT technique. Due to the excellent soft tissue contrast, the technique is well suited to the visualisation of soft tissues and internal organs (e.g., the brain, liver, etc.).

MPMCTA, PMCTA, PMA

These acronyms all refer to the technique known as multi-phase postmortem CT angiography, an imaging technique in which the blood vessels along with any mutations and damage can be visualised with the help of a contrast agent (Angiofil®) and a perfusion device (Virtangio®). The technique is also commonly referred to as PMCTA (postmortem CT angiography) or PMA (postmortem angiography) for short. This standardised technique makes it possible to fill the circulatory system under control, allowing reliable interpretation of the findings in the cardiovascular tissues.

3D surface scanning

3D surface scanning is a non-contact, optical measurement technique used to produce a three-dimensional image of the surface of a body or other object. This procedure provides even more precise models to scale, which can then be used for computer-assisted 3D reconstructions.

TWGPAM

The Technical Working Group Postmortem Angiography Methods is an international scientific research group which has set itself the goal of ongoing validation of postmortem angiography and publishes in internationally renowned journals.

Forensic medicine, pathology, anatomy

Medical examination of the deceased by means of an autopsy (postmortem examination) plays a central role in the education and training of doctors in the field of anatomy, in the quality assurance of clinical practice, in the field of pathology and in the administration of justice when clarifying unusual deaths in the field of forensic medicine.
For centuries, a surgeon's scalpel had been the method of choice.

Advances in medical imaging

With the exponential technological advance in medical imaging which began towards the end of the last century and with the possibility of 3D surface visualisations to scale, the demand emerged for transposing this technology to the medical and scientific fields mentioned above: anatomy, pathology and forensic medicine.

Implementation in postmortem forensic radiology

The renowned American forensic radiologist Gil Brogdon drew attention to the possibilities for employing the different modalities of the imaging techniques to examine the deceased in his book "Forensic Radiology" in 1998 and called for interdisciplinary cooperation between radiology and forensic medicine *(Images 1 and 2).*

"Virtopsy" research project – University of Bern

This call was answered at the turn of the millennium when the "Virtopsy" research project (see www.virtopsy.com) was launched under the supervision of Prof. R. Dirnhofer and Prof. P. Vock from the Institute of Forensic Medicine and Radiology at the University of Bern, Switzerland.

It soon became clear that the combined employment of an array of imaging techniques could produce a highly accurate 3D visual record of the deceased. This "facsimile", in other words a structurally identical reproduction of the subject's body, can then be scrutinised in all its details on a computer screen.

The scientific basis of imaging techniques such as computed tomography and magnetic resonance imaging has already been put to the test for many years – particularly of course with regard to its reliability in the field of clinical application on patients. A number of protocol adjustments were required for it to be possible to employ the same imaging techniques on the dead. This has now been accomplished and also published. Corresponding SOPs (standard operating procedures) are available.

However, intensive development work on the postmortem visualisation of the corpse's blood vessels was a top priority when it came to the idea of the Virtopsy project as an evolutionary phase towards minimally invasive autopsy.

The issue was that there is no circulation of the blood in the dead, making it impossible to transport a contrast agent in order to depict the blood vessels.

The success of this new method is reflected in the recent presentation of the "Swiss ICT Special Award 2015" to the Institute of Forensic Medicine at the University of Zurich *(Image 3).*

Development of a reliable postmortem angiography technique

Ultimately, the solution to the problem was complete visualisation of the arteries, veins and capillaries of the circulatory system. To this end, Fumedica AG, a Swiss medical engineering company, developed not only the perfusion device required for this purpose, but also the corresponding contrast agent and application set for investigating the blood vessels after death *(Image 4 / Insert 1).* This laid the technological foundations for so-called multi-phase perfusion techniques, which considerably improved the reliability of the findings.

The techniques were then extensively tested and harmonised. The first comprehensive validation studies have also already been completed *(Insert 2).*

For instance, the Technical Working Group Postmortem Angiography Methods (TWGPAM) carried out a multi-centre study under the leadership of the University Centre of Legal Medicine at the University of Lausanne (Prof. Silke Grabherr), with the aim of validating multi-phase postmortem CT angiography (MPMCTA), defining its indications and demonstrating the benefits and limitations of the method, particularly in comparison with conventional autopsy.

The study provided an extensive and solid database for definitive integration of MPMCTA in routine forensic medical practice and thus its inclusion in courtrooms, but with the solution to the problem of postmortem angiography, the floodgates for integration of the imaging procedures with their different modalities such as CT, PMCTA and MRI in practical forensic medicine were also blown wide open once and for all.

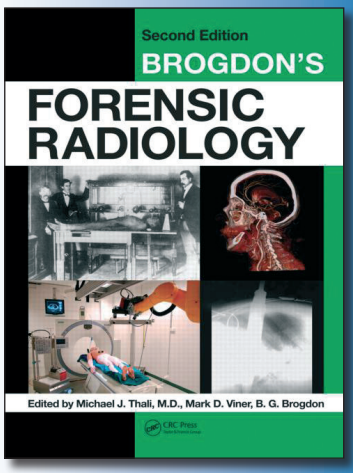


Image 1

Call for interdisciplinary cooperation

G. Brogdon, USA

G. Brogdon, Forensic Radiology (1998) 237.

Inspired by the continuous technological advances in the different modalities in imaging procedures, the author called for increased interdisciplinary cooperation:
«A rather sad commentary on the research examples cited and, indeed, on most forensic research employing radiologic methods and modalities, is that the overwhelming majority of investigators have been nonradiologists. Often they must struggle with substandard equipment and in ignorance of well-known radiologic tenets not published in their literature. On the other hand, most radiologists have little connection with the forensic sciences and are unaware of the research possibilities in that field, or of the problems that need solution. It is believed that forensic scientists in other disciplines would find radiologists in their area interested in cooperative efforts. Sharing of interdisciplinary skills and knowledge would improve the economy and effectiveness of investigative efforts, prevent some false starts and /or reinventions of well-worn wheels, and most important, expand scientific horizons. The two short chapters following are examples of modern applications of new radiologic modalities in forensic investigations.
One uses our most exciting new modality, magnetic resonance imaging, in postmortem studies and promises to be of great help to the forensic pathologist, the other is an example of the adoption of an industrial technique for application in the fields of forensic sciences and clinical medicine.»

Image 2

Image 3
Virtopsy, Virtobot

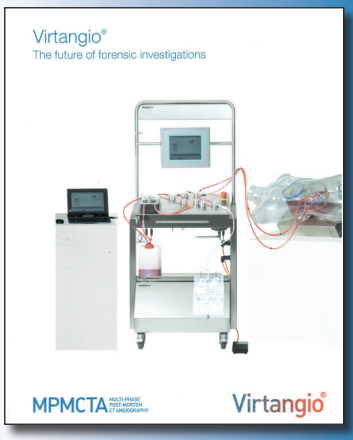


Image 4
Virtangio® device
Virtangio® set
Angiofil®

As such, the "proof of project" has now been established and the goal of a minimally invasive autopsy reached.

International impact on research

The international impact of this idea was subsequently reflected in the exponential increase in scientific publications dealing with forensic radiology around the world. For instance, the recently published study by M. Baglivo et al. showed a hundredfold increase in the volume of publications compared to the turn of the millennium when the "Virtopsy" project was launched *(Insert 3).*

In short, the results of these numerous publications show that postmortem imaging is not only equal to autopsy in many respects, but that these techniques can even achieve better results than conventional autopsy procedures (see Advantages of postmortem imaging techniques).
This also confirms that traditional autopsy can no longer be seen as the sole gold standard for forensic medicine, as was already suspected based on the imaging investigations performed by Donchin et al *(Insert 4).*

Academic specialisation at universities

The "Virtopsy" concept was first introduced to the public at the German Society of Legal Medicine's annual scientific conference in Interlaken, Switzerland, in 2001.

Now, 15 years on, not only has the number of academic publications on the subject of postmortem imaging increased substantially, the topic is also reflected in the strategy employed by universities when staffing their departments.

For example, in the last few years, all the chairs of forensic medicine at Swiss medical schools have been awarded to professors with academic profiles focused on the field of forensic imaging.

For example, the Institute for Forensic Medicine in Zurich is presided over by Prof. Thali, who has made substantial contributions to the field of surface scanning, among others.

At the University of Basel, the chair is held by Prof. Eva Scheurer, whose academic specialisation lies in clinical imaging and MRI imaging.

The forensic medicine chair in Bern is held by Prof. Christian Jackowski, who has made fundamental contributions to the field of postmortem imaging in sudden death cases.

Finally, Prof. Silke Grabherr, who only recently took over the chair for forensic medicine at the Universities of Lausanne and Geneva, made the decisive scientific breakthrough in the field of postmortem angiography.

This "Swissness" in forensic imaging at Swiss universities has now been complemented by the recent awarding of the chair at the University of Heidelberg in Germany to Prof. Yen, who is also an academically established specialist in the field of postmortem imaging. Together with Prof. Schenner, a radiologist at the German Cancer Research Centre, she has managed to put together a competitive, interdisciplinary research group for postmortem imaging.

This development in academic personnel at the various universities is evidence of the clear, innovative and irreversible direction being taken by these forensic medicine institutes. As such, it is no wonder that the people named are also continuously invited to be guest speakers at international forensic congresses.

A number of different institutes in the USA (Baltimore, Maryland, with Prof. David Fowler and Albuquerque with Prof. Kurt Nolte) and England (University of Leicester with Prof. G. Rutty) are also already run by directors whose academic specialisations lie in the field of postmortem imaging.

All of these academic personnel decisions at the top level show that the forensic scientific community around the world is well aware of the incipient paradigm shift.

Last but not least, the increasing purchasing of imaging devices such as CT, MRI and MPMCTA machines by institutes in different European and non-European countries is yet further confirmation of this trend.

Consequences for forensic medicine institutes

As a result of this, numerous forensic medicine institutes have installed their own CT scanners or entered into cooperations with radiology institutes.
New international specialist associations have been founded for forensic radiology and annual scientific meetings are now held (www.isfri.com).

There is even a new scientific journal dedicated to postmortem imaging (www.jofri.net). *(Image 5)*

In the USA, influenced by the positive research experiences at the University of Albuquerque in New Mexico and University of Baltimore in Maryland, the National Academy of Science has also recommended that imaging techniques such as CT, PMCTA and MRI should be viewed as best practices for forensic medical examinations *(Insert 5)*.

Against this backdrop, the AFIP (Armed Forces Institute of Pathology) was awarded a fund by the Defense Advanced Research Projects Agency (DARPA) to the tune of $4 million for the improvement of imaging techniques for examining the dead. This academic grant was the incentive for the scientific text-atlas: "Forensic Imaging" by Angela D. Levy and Theodore Harcke *(Image 6)*.

Legal acceptance

Against the backdrop of these scientific and medical developments, lawyers too began addressing the issue. A special mention here should be given to David Alexander Zimmermann's dissertation "Virtopsy und damit verbundene rechtliche Rahmenbedingungen und Auswirkungen" (Virtopsy and its associated legal parameters and impact).

This weighty volume deals with the legal situation and the introduction of the new techniques (CT, PMCTA, MRI) taking into consideration the aspects of the different codes of criminal procedure around the world. Australia has taken on a leading role and established the legal foundations in individual constituent states *(Image 7)*.

A detailed legal debate from the perspectives of the German, Swiss and Austrian criminal codes entitled "Der gläserne Körper im Gerichtssaal" (The Glass Body in the Courtroom) is due to be published soon. *(Image 8)*

Across Switzerland, the Swiss law enforcement authorities follow the example of the Institute of Forensic Medicine at the University of Bern, where "...autopsies are today preceded as standard by examinations using imaging procedures (CT and/or MRI). Depending on the result of these examinations it may be possible to dispense with autopsy." (Taken from the manual published in May 2014 by the public prosecutor's office in Bern.)

Use of CT, PMCTA and MRI techniques in pathology

However, it's not only in the field of forensic medicine but also in that of pathology, in other words the branch of medicine used for clinical quality control, that the imaging techniques are beginning to be incorporated. A number of very promising editorials have already appeared in various pathology journals. This medical speciality's interest in imaging techniques, especially postmortem angiography, is rooted in the fact that 5% to 10% of primary diagnoses in hospital environments are still incorrect even today.

For example, studies conducted at the University of Hamburg have shown that the employment of imaging and postmortem angiography results in considerable improvements in the recording of the findings required for correct assessment.

Building on the positive results of the research group in Hamburg, a joint study coordinated by the Universities of Bern, Basel and Hamburg is set to commence in the near future studying the use of postmortem angiography in the fields of emergency cardiac medicine, interventional cardiology, cardiac surgery and intensive cardiac medicine.

On a similar note, Gil Brogdon's vision also looks set to come true, with postmortem imaging leading to a revival of the old clinico-pathological conference (CPC) *(Image 9)*.

Use in the field of anatomy

The medical speciality of anatomy has also begun to integrate postmortem angiography in its roles and research areas *(Insert 6)*.

Costs of imaging procedures

Publications from Rotterdam and cost analyses from the University of Maryland, Baltimore, Chief Medical Examiner David Fowler, have already confirmed positive cost-efficiency of postmortem imaging procedures such as CT, MPCTA, MRI, etc., in the future. This cost effect is based not only on the lower operating costs in comparison with conventional autopsy, but also on possible savings on investigations, more efficient forensic procedures due to image screening and significant cost savings as a result of subsequent expert reports. This cost-saving effect has also been confirmed at international congresses (RSNA) *(Insert 7)*.

Image 5

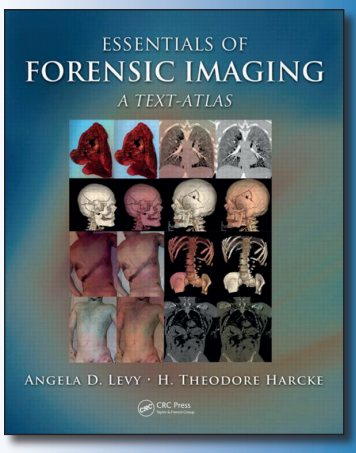


Image 6
"Forensic Imaging" atlas, USA 2011

Image 7
Book on the legal aspects of postmortem imaging – worldwide (approx. 600 pages)

Image 8
The Glass Body in the Courtroom

Reactions of popular scientific media

Local and international media have also caught on to the fact that the integration of imaging techniques such as CT, MPCTA, MPMCTA, MRI, etc., constitutes a "paradigm shift". For example, corresponding positive coverage has been observed in renowned magazines such as Science and The NY Times as well as on CNN, NZZ, etc. *(Image 10 / Insert 8).*

Raised awareness among imaging device manufacturers:

- After the first forensic medicine congress dealing with the concept of a minimally invasive autopsy, a Virtopsy, in 2001, it was only a short time before Siemens reacted with an advertising slogan for the use of their CT machines for forensic applications: "Get a clear image – in every forensic case!" *(Images 11 and 12).*
- As forensic imaging began to be implemented in German forensic medicine institutes, Philips published an advertising brochure entitled: "Dem Tod auf der Spur" (Following death's trail).
- In the USA, GE rapidly incorporated technical modifications into their CT devices for forensic applications at the AFIP (American Forensic Institute of Pathology).
- And, finally, Toshiba equipped the Victorian Institute in Melbourne, Australia, with its imaging equipment.
- Fumedica AG, a Swiss medical engineering company, developed reliable technological equipment comprising a perfusion device (Virtangio®), contrast agent (Angiofil®) and application set (Virtangio set®) for the visualisation of the blood vessels (MPMCTA).

Outlook

After 15 years of research in the field of forensic imaging, one thing is clear: autopsy truly is not the gold standard for gathering findings from a body any longer. This hypothesis was proposed by Donchin et al. almost 20 years ago and has now been confirmed by a whole range of imaging research results.

Does that mean that imaging with all of its modalities developed for forensics over the last 15 years, such as surface scanning, CT, PMCTA, MPMCTA, MRI, image-guided biopsy etc., is now sufficient by itself to provide the standard of evidence required in criminal proceedings for postmortem forensic examinations?

Zimmermann referenced a study by Jeffrey et al dealing with this very question. The authors also came to the same conclusion that the title of "gold standard" no longer belongs to autopsy alone, but rather the latter needs to be complemented with a postmortem CT scan.

However, Zimmermann also noted critically that this study was conducted prior to the development of MPCTA, in other words before it was possible to visualise the blood vessels, and that this additional imaging modality can also provide substantially more information.

This statement has now been confirmed by the MPMCTA publications of the research group in Lausanne, according to which it is actually possible to collect further information when MPMCTA is employed as a complement to CT, and the findings agree with the autopsy results in 70-80% of cases.

These results were recently confirmed in a European multi-centre study and are reflected in a "Postmortem Angiography" atlas published by Springer at the end of 2015 *(Image 13).*

In addition, these positive research results achieved with PMCTA have also resulted in a book project named "Rechtsmedizin für Radiologen" (Forensic Medicine for Radiologists) announced by the research group in Heidelberg.

The volume, which will fill an important gap in the interdisciplinary cooperation between forensic medicine and radiology and also includes chapters on PMCTA, is set to be published in autumn 2016 by Thieme.

Finally, the book "Der gläserne Körper im Gerichtssaal" set to appear at the end of 2015 will be translated into English, making it accessible at an international level. With this step we look set to reach the tipping point at which, thanks to the enormous, precise visualisation qualities of medical imaging, the technique shift from traditional, centuries-old autopsy to postmortem imaging, will occur.

The primary structural decisions concerning the future availability of the imaging equipment have already been taken. For example, the University Hospitals in Hamburg

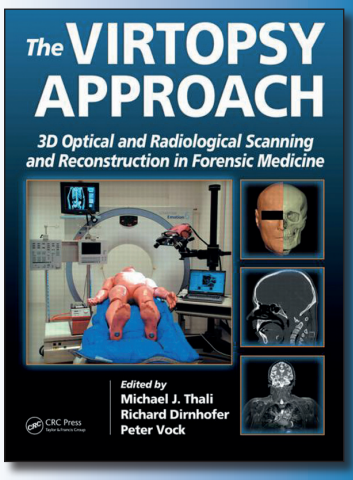


Image 9
"Virtopsy approach" atlas with foreword by G. Brogdon and note on revival of the CPC – Clinico-Pathological Conference

Image 10
Reactions to postmortem imaging

Image 11
Raised awareness among device manufacturers
PHILIPS

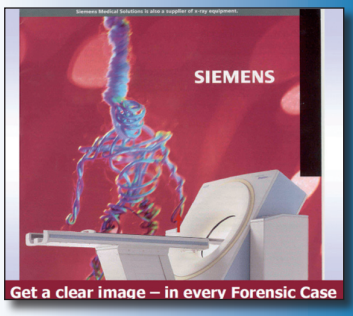


Image 12
Raised awareness among device manufacturers
SIEMENS

and Geneva are already planning to set up dedicated imaging facilities in their radiology departments and make them available for the medical specialities of forensic medicine, pathology and anatomy.

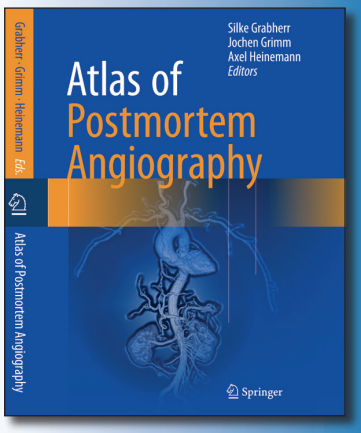


Image 13

Advantages of postmortem imaging techniques

In summary, the following advantages are presented by the imaging techniques CT, PMCTA, MPMCTA, MRI, etc.:

Imaging methods	Advantage of application in the justice system
Objective data collection "mechanised" objectivity without human influence	Independence from the specific forensic pathologist Considerably easier to obtain second opinions
Better reproducibility	Presentation of the findings themselves as evidence – not just the expert report
"Bloodless" documentation	"Non-traumatic" presentation of findings in the courtroom
Teleforensics	Not just two pairs of eyes, but multiple investigators
True-to-scale 3D facsimile of the body as an item of evidence	Real data forensic reconstructions are very accurate (e.g., road accidents, shootings, stabbings, etc.)
Postmortem angiography	Clear definition of sources of bleeding – in all trauma cases – in investigations into treatment errors – clear information following cardiac and vascular interventions – 3D record of bleeding in the soft tissues
Postmortem CT scans with simultaneous surface documentation	Possibility to make 3D morphometric comparisons, accurate in colour and scale, between the shape and size of injuries and the alleged weapon. Independent of place and time. – Reconstruction of road accidents and homicides based on real data – Contamination-free 3D comparisons – Joint examination and processing of a case by forensic scientists, police and judiciary. Introduction of the 3D model of the deceased/injured person into the 3D model of the crime scene
Clear detection of accumulations of gases in the body	Avoidance of gas embolisms in arteries and veins and escape of air into the chest, which are often overlooked because not visible at autopsy These findings can be relevant to the cause of death
Cause célèbre	Clear information given to the public
Detection of foreign bodies, parts of projectiles, weapons, etc.	Clear localisation of foreign bodies Reliable image-guided collection and storage
Non-destructive procedure	No debate over autopsy on religious grounds
Reliable recording of findings in areas difficult to dissect: head, neck, pelvis, peripheral vessel regions	Additional information from findings for establishment of the cause of death and forensic reconstruction
Archiving a "facsimile" of the corpse for use as evidence	Additions and subsequent expert opinions always possible at a later date (cremation, no need for exhumation)
Paradigm shift in terms of methodical workflow	Time and cost savings

MPMCTA MULTI-PHASE POST-MORTEM CT ANGIOGRAPHY | Virtangio® | Angiofil® | TWGPAM

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