Virtangio®
The future of forensic investigations

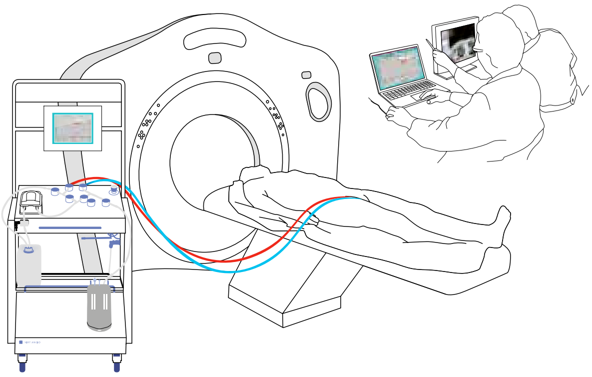
MPMCTA MULTI-PHASE POST-MORTEM CT ANGIOGRAPHY

Virtangio®

Virtangio®
The equipment

- the Virtangio® machine (injection machine)
- the single use tubing/cannula set
- the contrast agent Angiofil®

The equipment was developed by the company Fumedica AG in Muri/Switzerland in collaboration with the Legal Medicine Department of the University Lausanne/Switzerland (PD Dr Silke Grabherr). To perform MPMCTA, a CT scanner is needed.



Virtangio®
The use

The Virtangio® machine is placed beside the CT scanner. It works independently from the scanner and can be operated by remote control in the CT command room.

Before starting the angiography, an unenhanced CT scan of the body is performed. The body preparation for angiography takes about 15 minutes:

- small incision in the inguinal region on one side
- insertion of two cannulas into the femoral artery and vein
- connect the Virtangio® machine with the two cannulas fixed in the body with the tubing set
- entry of case information into the system

The angiography can start and the system guides the user systematically through the process.

To avoid vascular filling defects, the angiography consists of three different phases:

- arterial phase
- venous phase
- dynamic phase

During each phase, the machine automatically fills the respective blood vessels with the contrast agent mixture (Angiofil® with paraffin oil). While the CT scan in the arterial and venous phase is performed after the respective injection is complete, the scan for the dynamic phase is performed during the ongoing injection to simulate live perfusion. Depending on the CT scanner, performing the three phases takes between 10 – 30 minutes.

The Virtangio® machine provides the following advantages:

- injection can be performed volume- or pressure-controlled
- standard or individual protocols available
- machine stops in case of abnormal pressure loss or increase
- injection data are stored automatically

MPMCTA can even be performed on putrefied bodies, as long as the vascular system is intact.

The radiological interpretation of the images is done by a forensic radiologist together with the forensic pathologist. The image quality is comparable to or even better than corresponding images of living patients. By comparing the images of the three different phases and the native CT scan, artefacts and filling defects can be recognized and pathological findings verified. Trainings and guidelines for radiological interpretation are available.

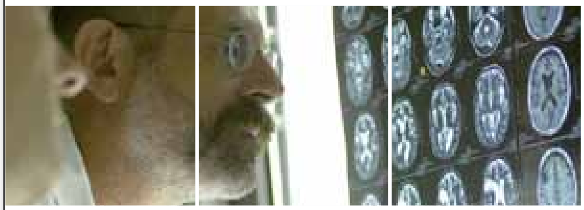
If necessary, a conventional autopsy can be performed after the angiography. With the exception of pulmonary fat embolism, there is no negative impact of the technique and the contrast agent on histology or toxicology; nevertheless it is recommended to take sensitive biopsy samples before the angiography if possible.

Indications	Advantages
• trauma cases like traffic accidents, sharp trauma, gunshot, blunt trauma • suspicion of cardio-vascular disease • suspicion of medical malpractice • any kind of unexpected and sudden death	• standardized, validated and minimally invasive procedure • controlled vascular filling in three phases (arterial, venous, dynamic) • closed system, no contamination • oily contrast agent with high radio opacity • no mixture with remaining blood • no oedemisation, no extravasation • training and guidelines for radiological interpretation

Performing MPMCTA with the Virtangio® equipment is a fast, standardized and minimally invasive procedure that can be easily implemented into the daily routine. The oily contrast agent does not mix with remaining blood and avoids an oedemisation of tissues (as frequently observed with most other contrast agents) due to a micro-embolization of the capillary vessels. The contrast agent can remain in the body after the examination. The single use tubing/cannula set avoids any contamination due to its closed system design.

Multi-phase post-mortem CT angiography (MPMCTA)

MPMCTA is a new, non-invasive and standardized method for forensic investigations. By scanning the body after injection of a contrast agent, the complete vascular system of the head, neck, thorax and abdomen can be visualized and reconstructed in detail. MPMCTA can “solve” 80-90% of the cases.



Only validated method

MPMCTA is currently the only validated method. An international study with nine European institutes (TWGPAM*) with more than 500 cases was finished at the end of 2014 and will be published in 2015. First, a MPMCTA was performed, followed by an autopsy. The comparison of the results showed that 80-90% of the pathological findings were detected with the angiography only. MPMCTA is even superior to autopsy in vascular and bone findings.

This means that an angiography would be able to replace an autopsy in the majority of the cases. In many other cases, MPMCTA will deliver relevant additional information in comparison to autopsy alone. In countries or cases where an autopsy is declined for religious or ethical reasons, this method can help to find the cause of death without an invasive examination.

*Technical Working Group Postmortem Angiography Methods

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Literature

Application of contrast media in post-mortem imaging (CT and MRI)
Grabherr S et al; Radiol Med 2015 Apr 5. [Epub ahead of print]; PMID: 25841652

Postmortem computed tomography angiography, contrast medium administration and toxicological analyses in urine
Palmiere C et al; Leg Med (Tokyo). 2014 Dec 12. pii: S1344-6223(14)00176-X. doi: 10.1016/j.legalmed.2014.12.005 [Epub ahead of print]; PMID: 25537625

Postmortem angiography using femoral cannulation and postmortem microbiology
Palmiere C et al; Int J Legal Med. 2014 Nov 8. [Epub ahead of print]; PMID: 25381195

The usefulness of post-mortem CT angiography in injuries caused by falling from considerable heights: Three fatal cases
Mokrane FZ et al; Diagn Interv Imaging. 2014 Oct 23;95(11):1085-1090. doi: 10.1016/j.diii.2013.08.010. [Epub ahead of print]; PMID: 25443333

Virtual autopsy with multiphase postmortem computed tomographic angiography versus traditional medical autopsy to investigate unexpected deaths of hospitalized patients: A cohort study
Wichmann D et al; Ann Intern Med. 2014 Apr 15;160(8):534-41. doi: 10.7326/M13-2211; PMID: 24733194

Advances in post-mortem CT angiography
Grabherr S et al; Br J Radiol. 2014 Apr;87(1036):20130488. doi: 10.1259/bjr.20130488; PMID: 24234582

Postmortem imaging of sudden cardiac death
Michaud K et al; Int J Legal Med. 2014 Jan;128(1):127-37. doi: 10.1007/s00414-013-0819-6. Epub 2013 Jan 16; PMID: 23322013

Postmortem computed tomography angiography vs. conventional autopsy: advantages and inconveniences of each method
Christine C et al; Int J Legal Med. 2013 Sep;127(5):981-9. doi: 10.1007/s00414-012-0814-3. Epub 2013 Jan 6; PMID: 23292183

Multi-phase postmortem CT angiography: recognizing technique-related artefacts and pitfalls
Bruguier C et al; Int J Legal Med. 2013 May;127(3):639-52. doi: 10.1007/s00414-013-0840-9. Epub 2013 Mar 21; PMID: 23515679

Surgical interventions with fatal outcome: utility of multi-phase postmortem CT angiography
Zerlauth JB et al; Forensic Sci Int. 2013 Feb 10;225(1-3):32-41. doi: 10.1016/j.forsciint.2012.05.013. Epub 2012 Jun 19; PMID: 22721937

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Int J Legal Med
DOI 10.1007/s00414-012-0814-3

ORIGINAL ARTICLE

Postmortem computed tomography angiography vs. conventional autopsy: advantages and inconveniences of each method

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Received: 25 September 2012 / Accepted: 20 December 2012

Abstract
Purpose Postmortem computed tomography angiography (PMCTA) was introduced into forensic investigations a few years ago. It provides reliable images that can be consulted at any time. Conventional autopsy remains the reference standard for defining the cause of death, but provides only limited possibility of a second examination. This study compares these two procedures and discusses findings that can be detected exclusively using each method.
Materials and methods This retrospective study compared radiological reports from PMCTA to reports from conventional autopsy for 50 forensic autopsy cases. Reported findings from autopsy and PMCTA were extracted and compared to each other. PMCTA was performed using a modified heart–lung machine and the oily contrast agent Angiofil® (Fumedica AG, Muri, Switzerland).
Results PMCTA and conventional autopsy would have drawn similar conclusions regarding causes of death. Nearly 60 % of all findings were visualized with both techniques. PMCTA demonstrates a higher sensitivity for identifying skeletal and vascular lesions. However, vascular occlusions due to postmortem blood clots could be falsely assumed to be vascular lesions. In contrast, conventional autopsy does not detect all bone fractures or the exact source of bleeding. Conventional autopsy provides important information about organ morphology and remains the only way to diagnose a vital vascular occlusion with certitude.
Conclusion Overall, PMCTA and conventional autopsy provide comparable findings. However, each technique presents advantages and disadvantages for detecting specific findings. To correctly interpret findings and clearly define the indications for PMCTA, these differences must be understood.

Keywords Forensic medicine · X-Ray computed tomography · Autopsy · Perfusion imaging · Angiography

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Published online: 06 January 2013

Introduction

The use of multi-detector computed tomography (MDCT) in postmortem investigations has become routine in many centers of legal medicine [1–6]. MDCT is a rapid and easy way to look inside the body and document findings. It offers the opportunity to consult data at any time, even after cremation or burial of the body. Furthermore, the handling of an MDCT unit is relatively easy, and its maintenance costs are affordable for certain institutes of legal medicine. The diagnostic value of MDCT compared to conventional autopsy has been addressed in multiple publications [7, 8].

Although native or unenhanced MDCT (without the injection of contrast agent) can show major vascular lesions such as aortic rupture [9], its most important limitation is its low ability to visualize the vascular system and soft tissue. By injecting contrast agent into the vessels, different parts of the vascular system are rendered visible [10–13]. Recent advances have made it possible to visualize the entire vascular system in a minimally invasive way [14, 15]. The performance of postmortem computed tomography angiography (PMCTA) appears to have important advantages, especially in detecting sources of hemorrhage [16, 17]. In the early twenty-first century, postmortem angiography was performed with little success due to the imaging and perfusion techniques [18, 19]. In 2008, Grabherr at al. introduced the use of a modified heart–lung machine to establish postmortem circulation, in turn allowing the injection of a contrast agent and constant perfusion of a body [20]. This technique has been further developed and standardized. Nowadays, it consists of the execution of at least one native computed tomography scan and three angiographic phases (arterial, venous, and dynamic). This multi-phase PMCTA (MPMCTA) [21] has been introduced as a routine investigation method at the University Centre of Legal Medicine in Lausanne. The combination of MPMCTA with conventional autopsy improves the results of postmortem investigations, as has been stated regarding the examination of the coronary arteries [22].

However, MPMCTA is still a new technique. In contrast, conventional autopsy consists of a systematic approach that has been known and used for centuries—one reason why it is recognized as the optimal method with which to detect findings that indicate an individual's cause of death. To define the limits, advantages, and overall diagnostic value of MPMCTA, it is necessary to compare the performance of this new method to the well-known technique of conventional autopsy. To our knowledge, this is the first such study.

This study will evaluate the diagnostic value of MPMCTA compared with native MDCT and conventional autopsy, and describe findings that can be detected exclusively by each method to define method-specific limitations and advantages.

Materials and methods

Subjects

A total of 50 human corpses with postmortem intervals ranging from a few hours to several days were included retrospectively in the study. The first nine bodies were donated by anatomical institutes, and a summary of the medical history of the diseased was made available. The other 41 cadavers underwent a forensic autopsy in our institute between September 2008 and February 2010. A consecutive sample method with no specific exclusion criteria was used to include autopsy cases. No choice was made concerning the indication for the medico-legal autopsy. Therefore, causes of death included trauma (e.g., stab wounds or traffic accidents), intoxication (e.g., drug or carbon monoxide intoxication), and natural death (e.g., heart attack or cancer-related complications). In each case, a radiological investigation including native CT scan and postmortem CT angiography was performed before the conventional autopsy. This study was approved by the local justice department and the ethics committee.

Radiological examination

Before starting any invasive incisions, an external examination of the body was performed by the forensic pathologist in charge of the case, and a native CT scan was done by the forensic radiographer of the institute. MDCT scans were performed using an eight-row CT unit (CT LightSpeed 8; GE Healthcare, Milwaukee, WI, USA) with the following scan parameters: field of view (FOV), 50 cm; slice thickness, 2.5 mm; interval of reconstruction, 2 mm; 120 kV; 280 mA (modulated); and noise index, 15. The scan was performed following the standard protocol of the institute, from the cerebral vertex to the pubic symphysis. Standard lung and bone filter reconstructions were acquired, and bone-reformatted images of the spine were extracted.

After the collection of postmortem liquid samples under CT guidance for toxicological analysis and the analysis of clinical biomarkers [21, 23], cannulation of the femoral vessels of one side was performed using 16F diameter cannulas for arteries and 18F cannulas for veins (MAQUET GmbH & Co. KG, Rastatt, Germany). MPMCTA was performed according to the standardized protocol proposed by Grabherr et al. [21], using a contrast agent mixture composed of 6 % of the oily liquid Angiofil® (Fumedica AG, Muri, Switzerland) and paraffin oil (paraffinum liquidum) with a Virtangio® perfusion device (Fumedica). For the arterial phase of MPMCTA, 1,200 ml of contrast-agent mixture has been injected into the femoral artery using a flow rate of 800 ml/min. Once this volume was injected, data acquisition of the arterial phase was completed using the following scan parameters: field of view, 50 cm; slice thickness, 1.25 mm; interval of reconstruction, 0.6 mm; 120 kV; 280 mA (modulated); and noise index, 15.

For the venous phase, 1,800 ml of contrast-agent mixture has been injected at a flow rate of 800 ml/min. Data acquisition was then obtained using the following scan parameters: field of view, 50 cm; slice thickness, 2.5 mm; interval of reconstruction, 1.2 mm; 120 kV; 280 mA (modulated); and noise index, 15. In order to perform the dynamic phase of MPMCTA, further 500 ml of contrast-agent mixture were

injected at a flow rate of 200 ml/min. The data acquisition of this phase was performed during the ongoing injection in order to mimic in vivo conditions. For this acquisition, the same scan parameters were used as in the venous phase of angiography.

Radiological interpretation

A complete radiological report, including native CT scan and CT angiography, was written jointly by two board certified radiologists (one specialized in vascular radiology and one specialized in neuroradiology) and one board certified forensic pathologist specialized in forensic radiology. These specialists did get major information about the case such as age of the deceased, circumstances of death or discovery of the body, short medical history if available, information obtained by witnesses, and most important findings of the external examination (same information as the forensic pathologist had prior to autopsy).

Findings that were identified and reported in the autopsy report but not in the radiological report were then cross-checked by one radiologist to define whether the finding was imperceptible or simply not reported during the first lecture.

Conventional autopsy

Autopsies were performed by the forensic pathologists in charge of the case (one board-certified forensic pathologist and one forensic pathologist-in-training). These experts were informed about the most important radiological findings prior to the autopsy, enabling them to adequately adapt their autopsy technique. The autopsy complied with local standards (examination of the cranial, thoracic, and abdominal cavities) and was in accordance with European standards [24]. A complete autopsy report was edited by the two forensic pathologists.

Data extraction

To compare the two procedures (radiological examination and autopsy), only macroscopic autopsy findings (excluding those from external examination, histology, and toxicology) were taken into account and extracted from the autopsy reports.

For each case, all reported signs were extracted from both radiological and autopsy reports by an independent observer. This process made it possible to recognize findings that were identified and reported by both methods, as well as those that were only mentioned by a single method.

All findings were also categorized by the type of tissue in which they were observed. Therefore, we distinguished between vascular (e.g. leak, rupture, and occlusion), bone (e.g., fracture, arthrosis, and defect), soft tissue (e.g., hematoma…), and parenchymal (e.g., lung or liver nodules, and lacerations) findings.

To define the importance of each finding to the solution of the respective case, two board-certified forensic pathologists independently classified each finding, without knowing if it was extracted from autopsy or radiological report, on a three-step Likert scale: "essential", "useful", and "not important". Experts were asked to "subjectively evaluate the importance of each finding in defining the cause of death". For example, in one case "Fracture of the 4th, 5th and 6th rib, and fracture of the sternum" was judged as "useful findings" only as these fractures were due to unsuccessful cardiopulmonary resuscitation that took place after death had occurred whereas in a cases of thoracic trauma, such fractures would be judged as "essential findings". To give another example, the presence of coronary sclerosis would be esteemed as essential finding in a case of sudden cardiac disease whereas it would only be classified as "useful finding" in a case of trauma. Typical "not important findings" were the description of degenerative changes of the spine or the presence of small gallstones. When experts disagreed, an intermediate category was generated. Therefore, in total, there were five ordinal values corresponding to "Essential finding" (important to solve the case), "Very useful finding" (helped to solve the case), "Useful finding" (good to know), "Less important finding" (may be mentioned), and "Not important finding" (not useful to mention).

Causes of death were defined from the overall conclusion, which includes all examinations. Cause of death was then categorized as due to polytrauma, other violent death, sudden cardiac death, or other natural death.

Statistical analysis

Kappa statistics were used to assess the reliability of pathologists' judgments when defining the relevance of each sign used to determine the cause of death. Next, we used the chi-squared test to test the significance level of observed differences between groups that had been classified by relevance of signs, nature of tissue, and cause of death. The significance level was set at 0.05, and P values did not take into consideration the lack of independence between signs from the same case. Results were confirmed using a generalized estimate equation that controlled for clustering effects. All statistics were performed by a certified statistician, using STATA 12.0 (StataCorp LP, College Station, TX, USA).

Results

Details of the 50 cases assessed are summarized in Table 1. From these 50 cases, a total of 582 findings were reported.

Table 1 Characteristics of observed cases (n=50)

Characteristic	Description
Sex, number of males (%)	39 (76.5 %)
Age	
Mean (SD)	52 years (19.6 years)
Median (range)	51 (15–89)
Cause of death, n (%)	
Polytrauma	11 (22 %)
Other violent death	13 (26 %)
Sudden cardiac death	17 (34 %)
Other natural death	9 (18 %)
Number of observed signs	
Mean (SD)	11.2 signs (8.9)
Median (range)	8 (1–49)
<3	1 (3.9 %)
3–10	28 (54.9 %)
11–20	15 (29.4 %)
>20	6 (11.8 %)

On a three-step Likert scale, overall agreement between the two assessors regarding the relevance of findings to the conclusion of the cause of death was 61.5 %. Two hundred eighteen of the discrepancies (97.3 %) concerned neighboring categories, while the six remaining findings were classified with a discrepancy of two categories. Therefore, even when Cohen's kappa was low (k=0.34; 95 % CI = 0.28, 0.41), the assessment was shown to be reliable when the ordinal value of the scale was taken into consideration ($ICC_{2,3}$= 0.573; 95 % CI = 0.481, 0.647).

Of the 463 findings reported at autopsy, 340 were initially reported by the radiologists (73.4 %; 95 % CI = 69.2, 77.4). Five radiological findings out of 459 (1.1 %; 95 % CI = 0.4, 2.5) were "missed" during the first lecture and identified during the second reading. Apparently, the ability to detect findings from the autopsy was not related to the cause of death (χ^2=1.73; df=3; P=0.630), but was mostly related to the nature of the lesion itself (χ^2=35.4; df=4; P<0.001). The proportion of findings detected by CT angiography was highest (91.3 %) for findings estimated as essential to defining the cause of death. This trend was independent of the type of tissue studied and the cause of death (Table 2).

Compared to autopsy or CT, MPMCTA was most efficient in detecting essential findings (Table 3). MPMCTA was highly efficient in detecting vascular signs (97.1 %) and bone findings (98.6 %, with bone filter reconstructions). However, it demonstrated some limitations regarding the detection of parenchymal findings (79.1 %), while autopsy demonstrated major limitations in detecting bone findings (58.9 %). These two methods were complementary, as 97.7 % of findings in parenchyma were detected by autopsy.

Useless findings for defining the cause of death were reported in both radiological and autopsy reports (Table 4), and varied from 14.7 % of reported findings for MPMCTA to 17.9 % for native CT scan.

Figure 1 illustrates the comparative abilities of imaging and autopsy to detect findings. Thirty of the 73 essential bone signs were detected by imaging alone, while nine of the 43 essential parenchymal findings were detected by

Table 2 Autopsy findings detected by CT angiography

	Overall n/N[a]	No importance	Little importance	Useful	Very useful	Essential	P value, chi-squared test
Type							
Vascular	115/131 (87.8 %)	0/0	6/9 (66.7 %)	36/43 (83.7 %)	18/22 (81.8 %)	55/57 (96.5 %)	0.014[c]
Bone	81/91 (89.0 %)	0/0	0/0	11/14 (78.6 %)	28/32 (87.5 %)	42/43 (97.7 %)	0.001[c]
Soft tissues	25/45 (55.6 %)	0/0	2/5 (40.0 %)	9/14 (64.3 %)	8/18 (44.4 %)	6/7 (85.7 %)	0.219[c]
Parenchyma	124/196 (63.3 %)	17/24 (70.8 %)	18/30 (60.0 %)	26/49 (53.1 %)	30/51 (58.8 %)	33/42 (78.6 %)	0.108
Cause of death							
Polytrauma	141/195 (72.3 %)	3/4 (75.0 %)	11/18 (61.1 %)	15/32 (46.9 %)	38/63 (60.3 %)	74/78 (94.9 %)	<0.001[c]
Other violent death	57/76 (75.0 %)	4/9 (44.4 %)	5/7 (71.4 %)	12/17 (70.6 %)	14/17 (82.3 %)	22/26 (84.6 %)	0.175
Sudden heart death	96/122 (78.7 %)	8/9 (88.9 %)	7/14 (50.0 %)	33/42 (78.6 %)	20/24 (83.3 %)	28/33 (84.8 %)	0.075
Other natural death	51/70 (72.9 %)	2/3 (66.7 %)	3/7 (42.9 %)	22/29 (75.9 %)	12/19 (63.4 %)	12/12 (100 %)	0.035[c]
All signs	345/463 (74.5 %)[b]	17/25 (68.0 %)	26/46 (56.5 %)	82/120 (68.3 %)	84/123 (68.3 %)	136/149 (91.3 %)	<0.001

[a] n the number of reported signs from CT angiography, N the total number of signs reported from the autopsy. n is a subset of N

[b] The proportion of detected signs was case dependent (P<0.05; chi-squared test)

[c] The number of observations by cell was too small for the chi-squared test to be used; Fischer's exact test was used instead

Table 3 Ability of CT alone, CT angiography, and autopsy to detect useful signs

	CT	CT angiography	Autopsy	*P* value
Useful				
Type				
Vascular	33/45 (73.3 %)	38/45 (84.4 %)	43/45 (95.6 %)	
Bone	12/15 (80.0 %)	12/15 (80.0 %)	14/15 (93.3 %)	
Soft tissues	5/14 (35.7 %)	9/14 (64.3 %)	14/14 (100 %)	
Parenchyma	26/51 (51.0 %)	28/51 (54.9 %)	49/51 (96.1 %)	
All signs	76/125 (60.8 %)	87/125 (69.6 %)	120/125 (96.0 %)	<0.001
Very useful				
Type				
Vascular	16/28 (57.1 %)	24/28 (85.7 %)	22/28 (78.6 %)	
Bone	52/56 (92.9 %)	52/56 (92.9 %)	32/56 (57.1 %)	
Soft tissues	2/18 (11.1 %)	8/18 (44.4 %)	18/18 (100 %)	
Parenchyma	29/52 (55.8 %)	31/52 (59.6 %)	51/52 (98.1 %)	
All signs	99/154 (64.3 %)	115/154 (74.7 %)	123/154 (79.9 %)	0.007
Essential				
Type				
Vascular	23/68 (33.8 %)	66/68 (97.1 %)	57/68 (83.8 %)	
Bone	72/73 (98.6 %)	72/73 (98.6 %)	43/73 (58.9 %)	
Soft tissues	5/9 (55.6 %)	8/9 (88.9 %)	7/9 (77.8 %)	
Parenchyma	32/43 (74.4 %)	34/43 (79.1 %)	42/43 (97.7 %)	
All signs	132/193 (68.4 %)	180/193 (93.3 %)	149/193 (77.2 %)	<0.001
Overall	307/472 (65.0 %)	382/472 (80.9 %)	392/472 (83.1 %)	

autopsy alone. Thirty of the 38 findings that were judged of no importance were of parenchymal origin.

As the radiological investigation showed clear advantages especially concerning bone findings, we investigated these findings in more details (Table 5). One hundred twenty-three fractures were observed on 22 cases. The number of fractures per case ranged from one to 33 fractures (median = 2). Thirty-nine fractures (31.7 %) were not reported during the autopsy. Missed fractures most often concerned the scapula (3/3; 100 %), the pelvis (5/7; 71.4 %), the skull (17/36; 47.2 %), and the spine (13/30; 43.3 %), and least of all the ribs, sternum and collar bone (1/40; 2.5 %), the lower limb (0/3; 0 %), and the hyoid bone (0/3; 0 %).

Discussion

The present study evaluated the diagnostic value of MPMCTA, particularly its additional value compared with

Table 4 Proportion of signs reported as not useful

	Native CT	CT angiography	Autopsy	*P* value
Type				
Vascular	7/79 (8.9 %)	7/135 (5.2 %)	9/131 (6.9 %)	
Bone	10/146 (6.8 %)	10/146 (6.8 %)	2/91 (2.2 %)	
Soft tissues	4/16 (25.0 %)	5/30 (16.7 %)	6/91 (2.2 %)	
Parenchyma	46/133 (34.6 %)	44/137 (32.1 %)	54/196 (27.5 %)	
Cause of death				
Polytrauma	16/171 (9.4 %)	16/204 (7.8 %)	22/195 (11.3 %)	
Other violent death	16/55 (29.1 %)	16/72 (22.2 %)	16/76 (21.0 %)	
Sudden heart death	28/97 (28.9 %)	28/114 (24.6 %)	23/122 (18.8 %)	
Other natural death	7/51 (13.7 %)	6/58 (10.3 %)	10/70 (14.3 %)	
All signs	67/374 (17.9 %)	66/382 (14.7 %)	71/463 (15.3 %)	0.575

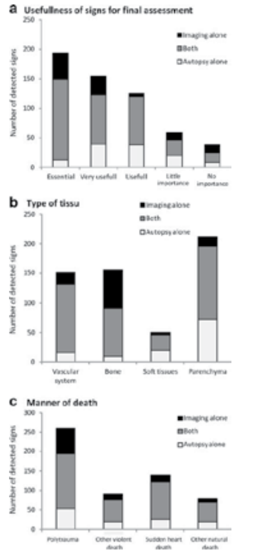


Fig. 1 The number of signs detected by each method (by postmortem radiology = MDCT + PMCTA, by both postmortem radiology and conventional autopsy, and by conventional autopsy alone) depending on importance (**a**), type of tissue (**b**), and manner of death (**c**)

native CT and advantages and limitations compared with conventional autopsy. We compared findings extracted from radiological reports with those extracted from conventional autopsy reports without taking into consideration the results of histology, toxicology, or additional examinations because the study's aim was to compare the results of autopsy and imaging, and not those of the entire medico-legal investigation to imaging alone.

To determine the overall value of MPMCTA, medico-legal cases were selected according to the availability of technical personnel during the initial implementation of this new technique, rather than in response to specific indications. Therefore, MPMCTA was applied to some cases for which this type of investigation would not have been indicated in routine practice. This consequence can be assimilated as a limitation of the study. However, different types of medico-legal cases are examined. We therefore limited bias concerning the application of this technique to only one kind of case. In addition, this procedure permitted to determine in which cases the performance of MPMCTA is of use, and therefore to define indications for its application.

To examine the impact of MPMCTA, we categorized different findings according to their importance for solving respective medico-legal cases. Although the two board-certified forensic pathologists who performed this grading have graduated from different European medico-legal schools, their estimations were similar regarding the importance of each finding.

As suspected at the beginning of our study, these results demonstrate that MPMCTA is highly efficient in the detection of vascular findings, particularly regarding hemorrhage sources (Table 3). However, some vascular findings were only detected by conventional autopsy. Such findings were bleedings into the vascular wall or ruptured atherosclerotic plaques that were too small to be detected by CT because they were essentially located in the coronary vessels. A similar observation has already been described by Michaud et al., who investigated the use of MPMCTA to examine coronary arteries [22].

The most important weakness of MPMCTA was its inability to visualize parenchymal findings. Although the performance of an MPMCTA can significantly improve the detection of parenchymal findings compared with native MDCT (from 65 % to 80.9 %), it still remains less sensitive than conventional autopsy. This difference can be easily explained by the fact that, even with the injection of contrast agent, contrast of the parenchyma is not high enough to diagnose lesions of inner organs. The implementation of MRI has already been proposed to overcome this disadvantage of forensic imaging, and initial studies have had promising results [25–27]. However, gaining access to an MRI unit may be even more difficult for forensic institutions than the performance of an MPMCTA.

Concerning the detection of bone findings, the radiological examination appears to clearly overcome conventional autopsy (Table 2). As shown by our results and in Table 5, standard autopsy can miss fractures in different regions of the body, especially in those which are difficult to access (scapula, spine, pelvis, and skull). Concerning the skull, missed fractures were mostly located in the facial bones which are not investigated routinely by a standard conventional autopsy. By using an appropriated filter of reconstruction, bone findings can be obtained by performing either native CT scan or MPMCTA.

Table 5 Fractures

Case no.	Skull f/F^a	Spine f/F^a	Rib, sternum, and collar bone f/F^a	Pelvis f/F^a	Others[b] f/F^a	All fractures f/F^a
5			0/1	1/1		1/2
11	0/2	0/2				0/4
13	10/13	3/8	0/5	1/1	2/6	16/33
14		0/1	0/1			0/2
16	3/9		0/4		0/1	3/14
5/11						
0/2						
17		2/3	0/5	3/3		
19			0/2			
22			0/1			0/1
23	1/4		1/3			2/7
24		5/8	0/1			5/9
26		1/2				1/2
29			0/1			0/1
0/2						
0/2						
0/2						
0/1						
3/10						
0/2						
0/2						
0/1						
0/6						
31			0/2			
35			0/2			
36			0/2			
38	0/1					
39	2/3	0/2	0/2	0/1	1/2	
40			0/2			
41			0/2			
42	0/1					
44	0/2	0/2	0/2			
45	1/1	2/2	0/2	0/1	0/1	3/7
Total missed at autopsy	17/36 (47.22 %)	13/30 (43.33 %)	1/40 (2.5 %)	5/7 (71.43 %)	3/10 (30 %)	39/123 (31.71 %)

[a] *f* the number of fractures missed at the autopsy, *F* the total number of fractures reported. *f* is a subset of *F*

[b] Four fractures from the leg from two cases detected by both autopsy and CT scan, three fractures of the scapula from two cases all undetected at the autopsy, and three hyoidal bone fracture all seen at the autopsy

One surprising result of this study was that MPMCTA appears to have greater sensitivity regarding soft tissue findings, such as small hemorrhages in subcutaneous fatty tissue or muscular tissue. This fact may be explained by the high sensitivity of contrast agents to detect the smallest extravasations (e.g., hematomas) but also by the fact that we have compared radiological data to findings from standard conventional autopsy, including opening three body cavities and examining soft tissue in the thorax and abdomen, but not including the dissection of soft tissue of the back. While the complete and detailed dissection of subcutaneous and muscular tissue of the back requires a special indication in conventional autopsy, the soft tissue of the back is always visualized during a standard CT acquisition, which includes the head, thorax, and abdomen. Therefore, MPMCTA may detect small hemorrhages in the muscle and subcutaneous tissue that would not necessarily be searched for during a conventional autopsy. This possibility may indicate that MPMCTA could also be used as a screen to decide whether dissection of the back is necessary.

Native CT scan and MPMCTA provided nearly the same percentage of non-useful findings (Table 4). The mean

number of findings reported as non-useful for conclusions of sudden cardiac death and other violent death is slightly higher for imaging than for autopsy, possibly because radiologists are used to a very detailed description of pathological changes that may play a role in clinical investigations, but not in forensic ones. A typical example is the description of degenerative lesions of the vertebral spine, which are mostly present in elderly subjects. As a matter of fact, elderly subjects are mostly victims of sudden cardiac death, and therefore the description of such "useless findings" may be observed more often in this group. Cases of other violent death were typically cases of intoxication. These also, showed more preexisting pathological changes that were described by radiologists without influencing the cause of death.

According to the results of our study, the indication to perform MPMCTA depends on the findings that are expected. MPMCTA is indicated if lesions are suspected in the vascular system according to the circumstances of death and the medical anamnesis (e.g., cases of polytrauma or sudden cardiac death). Cases in which a hemorrhage is suspected, or in which the vascular system has been modified by a surgical intervention (e.g., after coronary bypass), comprise a very special group of cases in which a detailed examination of the vascular anatomy is of importance. The performance of MPMCTA does not make sense in cases in which no vascular lesions are expected (e.g., cases of intoxication, drowning, or hanging). A vascular lesion should be suspected as a result of the reported data concerning the case, as well as after viewing the data from a native CT scan.

In our institute, the decision to perform MPMCTA is made by the forensic pathologist in charge of the case, who has all information necessary to know the circumstances of death and who will view radiological images of the native MDCT before starting the autopsy. This new technique can be implemented easily, particularly in institutes with access to a CT unit. Performance of a complete MPMCTA takes 1 to 1.5 h (depending on the MDCT unit used), including sample collections performed prior to the injection of the contrast agent. Thus, the entire postmortem investigation would be prolonged by up to 1.5 h, a change that appears to be possible, especially considering the advantages that can be obtained by using this technique. In our institute, the entire radiological examination is performed by forensic radiographers [26], which have been added to the forensic team. The multi-phase exploration can increase on one hand the quality of the obtained images as it allows a nearly complete filling of the vessels of the head, the thorax, and the abdomen and, on the other hand, it ameliorates also the radiological interpretation as it allows to verify findings by comparing different angiographic phases as described by Grabherr et al. [21]. However, the performance of the technique and the radiological interpretation of the images require specialized personnel.

If we consider all findings regardless of tissue type and importance, MPMCTA and conventional autopsy demonstrate nearly the same sensitivity concerning the detection of important findings. MPMCTA can increase the sensitivity of native CT scan from 65 % to 80.9 %, while conventional autopsy detects 83.1 % of all findings (Table 3). The result concerning essential findings is more surprising: autopsy reported 77.2 % and MPMCTA reported 93.3 % of all findings. For this reason, we esteem MPMCTA as a very powerful and useful tool that should be implemented as part of the routine medico-legal examination, if possible.

Acknowledgments This study was financially supported by the Promotion Agency for Innovation of the Swiss Confederation (KTI Nr.10221.1 PFIW-IW) and the Leenards Foundation, Lausanne, Switzerland.

Conflicts of interest None

References

1. Dirnhofer R, Jackowski C, Vock P et al (2006) VIRTOPSY: minimally invasive, imaging-guided virtual autopsy. Radiographics 26 (5):1305–1333, Review
2. Thali M, Dirnhofer R, Vock P (eds) (2009) The virtopsy approach: 3D optical and radiological scanning and reconstruction in forensic medicine. CRC, New York
3. Weustink AC, Hunink MGM, van Dijke CF et al (2009) Minimally invasive autopsy: an alternative to conventional autopsy? Radiology 250(3):897–904
4. Jeffery AJ (2010) The role of computed tomography in adult postmortem examinations: an overview. Diagn Histopathol 16 (12):546–551
5. O'Donnell C (2010) An image of sudden death: utility of routine postmortem computed tomography scanning in medico-legal autopsy practice. Diagn Histopathol 16(12):552–555
6. Poulsen K, Simonsen J (2007) Computed tomography as a routine in connection with medico-legal autopsies. Forensic Sci Int 171(2–3):190–7
7. Jacobsen C, Lynnerup N (2010) Craniocerebral trauma-congruence between postmortem computed tomography diagnoses and autopsy results: a 2-year retrospective study. Forensic Sci Int 194(1–3):9–14
8. Roberts IS, Benamore RE, Benbow EW et al (2012) Postmortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet 379(9811):136–42
9. Aghayev E, Sonnenschein M, Jackowski C et al (2006) Postmortem radiology of fatal hemorrhage: measurements of cross-sectional areas of major blood vessels and volumes of aorta and spleen on MDCT and volumes of heart chambers on MRI. AJR 187(1):209–215
10. Kennedy D, Laing C, Tseng L et al (2010) Detection of active gastrointestinal hemorrhage with CT angiography: a 4(1/2)-year retrospective review. J Vasc Interv Radiol 21(6):848–855
11. Karhunen PJ, Servo A (1993) Sudden fatal or non-operable bleeding from ruptured intracranial aneurysm: evaluation by postmortem angiography with vulcanising contrast medium. Int J Legal Med 106(2):55–59
12. Roberts I, Benamore R, Peebles C et al (2011) Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of post-mortem coronary CT angiography. Clin Radiol 66(7):645–650, Technical report

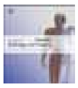
13. Saunders S, Morgan B, Raj V et al (2011) Targeted post-mortem computed tomography cardiac angiography: proof of concept. Int J Legal Med 125(4):609–616
14. Jackowski C, Thali M, Sonnenschein M et al (2005) Virtopsy: postmortem minimally invasive angiography using cross section techniques—implementation and preliminary results. J Forensic Sci 50(5):1175–1186
15. Grabherr S, Djonov V, Friess A et al (2006) Postmortem angiography after vascular perfusion with diesel oil and a lipophilic contrast agent. AJR 187(5):W515–W523
16. Kominato Y, Fujikura T, Hata Y et al (2006) A case of postoperative hemorrhage after a hysterectomy in which a bleeding point of the left uterine artery was identified by postmortem angiography. Legal Med 6(3):187–189
17. Ruder T, Ketterer T, Preiss U et al (2011) Suicidal knife wound to the heart: challenges in reconstructing wound channels with postmortem CT and CT-angiography. Legal Medicine 13(2):91–94
18. Grabherr S, Djonov V, Yen K et al (2007) Postmortem angiography: review of former and current methods. AJR 188 (3):832–838
19. Saunders S, Morgan B, Raj V, Rutty G (2010) Post-mortem computed tomography angiography: past, present and future. Forensic Sci Med Pathol 7(3):271–277
20. Grabherr S, Gygax E, Sollberger B et al (2008) Two-step postmortem angiography with a modified heart–lung machine: preliminary results. AJR 190(2):345–351
21. Grabherr S, Doenz F, Steger B et al (2011) Multi-phase postmortem CT angiography: development of a standardized protocol. Int J Legal Med 125(6):791–802
22. Michaud K, Grabherr S, Doenz F, Mangin P (2012) Evaluation of postmortem MDCT and MDCT-angiography for the investigation of sudden cardiac death related to atherosclerotic coronary artery disease. Int J Cardiovasc Imaging 28(7):1807–1822
23. Schneider B, Chevallier C, Dominguez A (2011) The forensic radiographer: a new member in the medicolegal team. Am J Forensic Med Pathol 33(1):30–36
24. Brinkmann B (1999) Harmonisation of medico-legal autopsy rules. Int J Legal Med 113(1):1–14
25. Jackowski C, Warntjes MJ, Berge J et al (2011) Magnetic resonance imaging goes postmortem: noninvasive detection and assessment of myocardial infarction by postmortem MRI. Eur Radiol 21(1):70–8
26. Yen K, Thali M, Aghayev E et al (2005) Strangulation signs: initial correlation of MRI, MSCT and forensic neck findings. J Magn Reson Imaging 22(4):501–510
27. Bouchireb K, Teychene AM, Rigal O et al (2010) Post-mortem MRI reveals CPT2 deficiency after sudden infant death. Eur J Pediatr 169(12):1561–1563

Journal of Forensic Radiology and Imaging 1 (2013) 3–9

Contents lists available at SciVerse ScienceDirect

Journal of Forensic Radiology and Imaging

journal homepage: www.elsevier.com/locate/jofri



The rise of forensic and post-mortem radiology—Analysis of the literature between the year 2000 and 2011 ☆

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ARTICLE INFO

Article history:
Received 17 September 2012
Received in revised form
22 October 2012
Accepted 23 October 2012
Available online 8 December 2012

Keywords:
Forensic radiology
Virtopsy
Post-mortem imaging
Literature analysis

ABSTRACT

Objective: It was the aim of this study to investigate the evolution of published literature in the field of post-mortem and forensic radiology, determine what technology is most widely used, identify primary research topics, and uncover areas where the evidence basis for post-mortem and forensic radiology is lacking.
Materials and methods: We performed an online literature search using 62 different combinations of search terms to identify articles on post-mortem and forensic radiology published between the year 2000 and 2011. For each publication included in the study, the following pieces of information were retrieved: title and abstract, author affiliation, year of publication, name of journal, type of article, and article language. Publications were categorized based on content, imaging modalities, use of additional techniques, and study population.
Results: A total of 661 publications were analyzed. Publications related to post-mortem and forensic radiology experienced a tenfold increase over the last 10 years. The majority of all publications focused on the documentation of injury or disease and identification of human remains. Computed tomography (CT) is chiefly used to investigate traumatic injury, magnetic resonance (MR) to assess cardio-vascular and cerebral disease, and radiographs to identify human remains. Other techniques are only rarely used. Over 40 countries worldwide contributed to the field during the study period.
Conclusions: This study provides evidence that scientific publications on forensic and post-mortem radiology grew significantly between the year 2000 and 2011. During this decade, forensic and post-mortem radiology rose from an obscure topic to a relevant field in the forensic sciences.

1. Introduction

Diagnostic radiology was rapidly adopted by the forensic sciences: within a few years after the discovery of x-rays in 1895, radiographs were introduced as evidence in court to visualize a retained bullet in the leg of a victim of attempted murder [1]. In the course of the following three decades, radiographs were used to document injury or disease, to detect bombs and contraband in mail and baggage and to determine the identity of unknown decedents [2]. Computed tomography (CT) was introduced to forensic sciences in the late 1970s by Wüllenweber et al. to document gunshot injuries [3]. Nevertheless, nearly 20 years later, by the end of the 20th century Prof. Gil Brogdon remarked in the preface to the first edition of his benchmark textbook *Forensic Radiology*, that there was still "no general appreciation of the extent of the radiological potential in the forensic sciences." [4]. As if spurred by Prof. Brogdon's lamentation, a number of forensic pathologists and radiologists across the world began to assess the potential of advanced imaging technologies in forensic sciences. At the turn of the new millennium, Profs. Dirnhofer and Vock launched the Virtopsy project in Switzerland to implement modern imaging technologies in forensic practice, including three-dimensional (3D) photogrammetry and surface scanning to document patterned injuries [5–7].

☆ Parts of this study were presented at the Congress of the International Society of Forensic Radiology and Imaging (ISFRI) 2012.

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http://dx.doi.org/10.1016/j.jofri.2012.10.003

First results of the Virtopsy project were presented at the Congress of the German Society of Legal Medicine in Interlaken (Switzerland) in 2001. By 2002, Bisset et al. had published a report regarding their experience with post-mortem magnetic resonance (MR) imaging in the UK. In the same year, Thali et al. coined the expression "virtual autopsy" [8,9]. Since then, the field of forensic radiology has undergone rapid expansion and some practitioners suggest it is and should become a distinct subspecialty of forensic medicine and radiology [10]. Today, post-mortem whole-body imaging prior to autopsy is a standard practice in many institutes across the world [11]. Over the same period, a large number of scientific articles and several textbooks on post-mortem and forensic imaging were published [12–18].

It was the aim of this study to investigate the evolution of the literature published online on Medline and PubMed in the field of post-mortem and forensic radiology between the year 2000 and 2011, determine what technology is most widely used, identify the primary research topics, and uncover current deficiencies in the evidence basis for post-mortem and forensic radiology.

2. Materials and methods

For this study, no ethics board approval or consent of any individual was necessary.

2.1. Literature search

We performed a literature search to identify peer-reviewed, scientific articles on post-mortem and forensic radiology published on Medline and PubMed with online publication dates between January 01, 2000 and December 31, 2011. Four prefix search terms (forensic, postmortem, post-mortem, and post mortem) were individually and separately combined with fifteen suffix search terms (radiology, imaging, computed tomography, CT, computed tomography angiography, CT angiography, CTA, magnetic resonance, MR, sonography, ultrasound, ultrasonography, surface scanning, and photogrammetry). The search terms "virtual autopsy" and "Virtopsy" were searched for separately, resulting in a total of 62 search queries. Publications were included in the study if the search terms appeared in either the title and/or the abstract of the paper.

To quantify the development in forensic radiology in relation to other medical specialties we performed seven additional search queries: three general medical terms (patient, treatment, and surgery), three radiologic keywords (radiology, CT/computed tomography, and MR/magnetic resonance), and the term forensic (excluding all suffix terms listed above) were searched for separately on Medline and PubMed. The number of publications featuring one of these seven search terms, in the title or abstract, was noted separately for each year from 2000 to 2011. The annual quantity of articles with "CT/computed tomography", "MR/magnetic resonance", and "radiology" were merged to one final number of annual publications labeled "general radiology". Publications featuring "patient", "treatment", or "surgery" were collectively labeled "general medicine".

2.2. Data collection—phase 1

For each publication included in the study, the following pieces of information were retrieved: title and abstract of the article, affiliation of the first author (including name of the city and country), year of publication, name of the journal (including rank and impact factor), the type of article (original research, technical note, case report, review, or letter to the editor), and the language in which the article was written. Each publication was categorized based on the principal imaging modalities (radiography, CT, MR, ultrasound, and surface scanning/photogrammetry), the use of additional devices (angiography and biopsy), the general radiologic category (identification, detection of foreign objects, documentation of injury or disease, description of normal post-mortem findings, or educational articles on the role of imaging in forensic sciences) and the number and type of subjects included (human adults, human infants/children, animals, models). The category, "description of normal post-mortem findings," encompasses imaging findings that may develop after death such as hypostasis (lividity), clotting, cooling, gas formation, adipocere, and mummification.

2.3. Data collection—phase 2

In Phase 2, all manuscripts categorized under documentation of injury or disease were classified into natural causes of death, unnatural causes of death, and imaging of the living. Publications on natural causes of death were further organized according to the principal organ system involved (diseases of the central nervous, cardio-vascular, respiratory, or musculoskeletal system, diseases of abdominal and retroperitoneal organs, and mixed case collections). Publications on unnatural causes of death were organized according to the predominant mechanism of injury (blunt force trauma, penetrating injuries, gunshot and blast injuries, thermal injury, drowning, hanging and strangulation, intoxication, and mixed case collections).

2.4. Data analysis

To compare the evolution of forensic radiology in relation to general medicine, general radiology, and general forensic medicine (excluding forensic imaging) we compared the annual increase of publications in each field. Descriptive statistics and percentages were calculated to analyze and present the data.

3. Results

3.1. Comparison between forensic radiology and other medical specialties

Our query retrieved 661 publications matching our search terms. Publications related to post-mortem and forensic radiology grew from only 12 articles in the year 2000, to 159 (1225% increase) articles in 2011. This represents more than a tenfold increase of the number of annual publications. Over the same period, the number of annual publications per year in other specialties only doubled: from 29,460 publications to 58,873 (100% increase) in general medicine, 5264 publications to 12,158 (131% increase) in general radiology, and 273 publications to 590 (116% increase) in general forensic sciences (excluding imaging) (Fig. 1). The relative contribution of forensic radiology and imaging to the fields of general radiology and general forensic sciences has grown from 0.2% and 4.2% respectively in 2000, to 1.3% and 21.2% respectively in 2011.

3.2. Categories and topics of publications in post-mortem and forensic imaging

The majority of all 661 publications focused on the documentation of injury or disease (51%, $n=340/661$) and identification (22%, $n=143/661$), followed by documentation of normal post-mortem findings (16%, $n=109/661$), educational articles on the role of imaging (8%, $n=55/661$), and the documentation of foreign objects (2%, $n=14/661$). Regarding the documentation of injury or disease, 52% ($n=176/340$) were related to unnatural causes of death, 45% ($n=152/340$) to natural causes of death, and 4% ($n=12/340$) to living subjects. In cases of unnatural causes of death, the principal focus of research lies on injuries related to blunt force trauma and gunshots (43%, $n=76/176$ and 19%, $n=33/176$ respectively). Topics with the lowest numbers of published research cover radiologic findings of intoxication (3%, $n=5/173$) and thermal injuries (3%, $n=5/176$) (Fig. 2). The main areas of investigation in cases of natural causes of death were diseases of the central nervous and cardiovascular system (45%, $n=69/152$; and 27%, $n=41/152$ respectively). Diseases of the respiratory tract (3%, $n=5/152$) and of the abdominal organs (2%, $n=3/152$) represent the two topics with the lowest numbers of published research on imaging of natural causes of death (Table 1).

3.3. Modality of choice in forensic and post-mortem imaging

Imaging technologies were actively used in 606/ 661 publications. The other 55/661 publications represent review-type articles, where the application of imaging is discussed but not actively applied. In 69% ($n=419/606$) of the non-review type articles, a single imaging modality was used (CT 53%, $n=217/419$; MR 36%, $n=151/419$; radiography 9%, $n=39/419$; ultrasound 2%, $n=8/419$; surface scanning 1%; $n=4/419$). Further investigation of all single-modality studies revealed that both CT and MR are primarily used to document injury or disease (53%, $n=116/217$ and 61% $n=92/151$ respectively). CT is chiefly used in cases of unnatural deaths (77%, $n=89/116$). Ninety-seven percent ($n=86/89$) of these studies are related to gunshot injuries and trauma. MR is primarily used in cases of natural deaths (86%, $n=79/92$). Ninety-five percent ($n=75/79$) of these studies are related to diseases of the cardiovascular or central nervous system. Radiographs were mainly used in studies related to identification of human remains (79%; $n=31/39$). In 31% ($n=187/606$) of all scientific publications, more than one imaging modality was used. CT and MR were used in combination in 36% ($n=68/187$) of all multi-modality studies, which corresponds to 11% ($n=68/606$) of all studies. Both post-mortem angiography and biopsy was used in a small number of publications (angiography: 5%; $n=33/606$, biopsy: 6%; $n=35/606$). Photogrammetry and three-dimensional surface scanning are used in 3% ($n=21/606$) of all scientific publications (Table 2).

Fig. 1. Comparison between forensic radiology and other medical specialties. Publications related to post-mortem and forensic radiology grew from only 12 articles in the year 2000, to 159 (1225% increase) articles in 2011. Over the same period, the number of annual publications in other specialties only doubled.

Table 1
Categories and topics of publications.

Topic	*n*	%
All publications	661	100
Documentation of injury and disease	340	51
Identification of human remains	143	22
Detection of foreign objects	14	2
Description of normal findings	109	16
Articles on the role of imaging	55	8
Documentation of injury and disease	340	100
Non-natural causes of death	176	52
Natural causes of death	152	45
Imaging of the living	12	4
Non-natural causes of death	176	100
Blunt force trauma	76	43
Gunshot injuries	33	19
Mixed findings	23	13
Penetrating trauma	16	9
Drowning	10	6
Strangulation	8	5
Intoxication	5	3
Thermal injuries	5	3
Natural causes of death	152	100
Central nervous system	69	45
Cardiovascular system	41	27
Mixed findings	26	17
Musculoskeletal system	8	5
Respiratory system	5	3
Abdominal findings	3	2

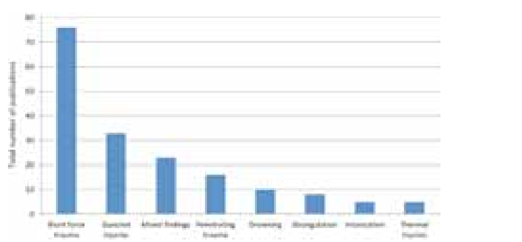

Fig. 2. Topics in publications on unnatural causes of death. In publications on unnatural causes of death, the principal research focus was on blunt force trauma and gunshots (43%, $n=76/176$ and 19%, $n=33/176$, respectively). There were very few publications on radiologic findings of intoxication (3%, $n=5/173$) and thermal injuries (3%, $n=5/176$).

3.4. Demographic distribution of subjects

The majority of all publications discusses imaging findings in humans (91%, $n=601/661$), chiefly adults (89%, $n=532/601$) and only rarely children (11%, $n=69/601$). A small number of studies was performed in animals (6%, $n=41/661$) or anthropomorphic models (2%, $n=15/661$). A negligible number of studies involved both humans and animals (< 1%, $n=4/661$).

3.5. Types of publications

Overall, more than half of all manuscripts (54%, $n=360/661$) were published as Originals Research, followed by Case Reports (23%, $n=149/661$), Reviews (11%, $n=72/661$), Technical Notes (10%, $n=68/661$), and Letters (2%, $n=12/661$).

The majority of Original Research publications investigates specific findings of injury or disease (49%, $n=175/360$) or describes normal (post-mortem) imaging findings (22%, $n=79/360$). Case Reports chiefly describe single observations of injury or disease (82%, $n=122/149$). Review articles and letters mostly emphasize the role of imaging (38%, $n=27/72$ and 50%, $n=6/12$ respectively). Technical Notes often feature new methods for the identification of human remains (31%, $n=21/68$) (Table 3).

3.6. Geographic distribution and language

Over the last decade, 41 countries from five continents have contributed to the field of post-mortem and forensic imaging. The majority of publications originate from Europe (65%, $n=427/661$), followed by Asia (16%, $n=105/661$), America (15%, $n=98/661$), Australia (4%, $n=27/661$), and Africa (< 1%, $n=3/661$) (Fig. 3 and Table 4). The five single countries with the highest number of publications are Switzerland (21%, $n=138/661$), UK (12%, 80/661), USA (11%, $n=75/661$), Germany (9%, $n=57/661$), and Japan (7%, $n=45/661$) (Fig. 4). The overwhelming majority of all manuscripts were written in English (91%, 604/661). Non-English articles were primarily written in Chinese (2%, $n=16/661$), Polish (2%, $n=10/661$), German (1%, $n=9/661$), and French (1%, $n=7/661$). The remaining articles were in Japanese, Danish, Finnish, Russian, Czech, Portuguese, Spanish, or Dutch.

3.7. Publishing journals

The 661 articles were published in 197 different peer-reviewed journals. However, 37% ($n=243/661$) of the manuscripts were published in 5 of these 197 journals, all of them devoted to forensic medicine; i.e. Forensic Science International (13%; $n=87/661$), Journal of Forensic Sciences (8%; $n=54/661$), Legal Medicine (Tokyo) (6%; $n=40/661$), International Journal of Legal Medicine

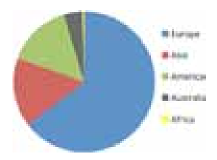

Fig. 3. Origin of publications by continent. The majority of publications originate from Europe (65%, $n=427/661$), followed by Asia (16%, $n=105/661$), America (15%, $n=98/661$), Australia (4%, $n=27/661$), and Africa (< 1%, $n=3/661$).

Table 2
Modality of choice in post-mortem and forensic imaging

Topic	All modalities		CT only		MR only		RX only		US only		SSC only	
	n	%	CT	%	MR	%	RX	%	US	%	SSC	%
All publications with active use of imaging	606	100	217	36	151	25	39	6	8	1	4	1
Documentation of injury and disease	340	56	116	53	92	61	5	13	6	1	4	1
Identification of human remains	143	24	70	32	5	3	31	79	2	0	0	0
Detection of foreign objects	14	2	9	4	1	1	0	0	0	0	0	0
Description of normal findings	109	18	22	10	53	35	3	8	0	0	0	0
Documentation of injury and disease	340	56	116	53	92	61	5	13	6	75	4	100
Non-natural causes of death	176	52	89	77	7	8	2	40	2	33	4	100
Natural causes of death	152	45	24	21	79	86	2	40	4	67	0	0

CT = computed tomography; MR = magnetic resonance imaging; RX = radiographs; US = ultrasonography; SSC = surface scanning

Table 3
Types of publications

Topic	All modalities		Original Research		Case Reports		Reviews		Techn. Notes		Letter	
	n	%	n	%	n	%	n	%	n	%	n	%
All publications	661	100	149	100	12	100	360	100	72	100	68	100
Documentation of injury and disease	340	51	122	82	3	25	175	49	20	28	20	29
Identification of human remains	142	21	16	11	1	8	87	24	18	25	21	31
Detection of foreign objects	14	2	4	3	2	17	6	2	0	0	2	3
Description of normal findings	109	16	6	4	0	0	79	22	7	10	17	25
Articles on the role of imaging	55	8	1	1	6	50	13	4	27	38	8	12

INSERT 3

(6%; $n=38/661$), and American Journal of Forensic Medicine and Pathology (4%; $n=24/661$). An additional 12% ($n=90/661$), appeared in the journals ranked 6–12 , including one additional international forensic journal (Forensic Science, Medicine and Pathology (2%; $n=13/661$)); one journal dedicated to forensic odontology (Journal of Forensic Dental Sciences (2%; $n=11/661$)); four imaging-related journals (European Journal of Radiology (2%; $n=15/661$), Neuroimage (2%; $n=13/661$), American Journal of Roentgenology (2%; $n=11/661$), Radiation Medicine (2%; $n=11/661$)); and the Chinese Journal of Forensic Medicine (Fa Yi Xue Za Zhi, 2%; $n=16/661$). Overall, 50% of all publications ($n=333/661$) were published in these 12/197 journals (Fig. 5).

4. Discussion

This study provides evidence that scientific publications on forensic and post-mortem radiology grew significantly between the year 2000 and 2011. During this decade, forensic radiology rose from a rather obscure topic to a relevant field in the forensic sciences.

The number of peer-reviewed articles on post-mortem and forensic radiology and imaging has increased from a dozen publications in 2000 to over a dozen per month in 2011. Over the same period, the number of published articles in general medicine, general radiology and general forensic medicine only doubled. This relative difference indicates that forensic radiology is a rapidly growing medical subspecialty.

Our analysis revealed that the primary topics of research in post-mortem and forensic imaging are: the documentation of injury or disease, the identification of human remains, the description of normal (post-mortem) findings, and the detection of foreign objects. This stands in agreement with Brogdon's definition of the scope of forensic radiology [2]. Unexpectedly, our search query retrieved a nearly equal amount of publications on natural and unnatural causes of death. There is a significant research effort using post-mortem imaging to perform radiologic–morphologic correlation outside the field of forensic sciences. This research focuses heavily on diseases of the cardiovascular and central nervous system. This finding is very important to forensic radiology, since diseases of the cardiovascular system are a frequent finding in forensic investigation. Therefore, many of these non-forensic publications are of great relevance to forensic imaging. Our findings, not surprisingly, uncovered the fact that research efforts in forensic radiology are focused on traumatic findings. There is a relative overrepresentation of studies on gunshot injuries, especially when compared to the small number of studies dedicated to imaging findings of drug abuse and intoxication, which contribute considerably to the case load of forensic investigations [19–23].

Our results indicate that CT is the modality of choice to document injury in cases of unnatural causes of death. This observation concurs with the often repeated statement that CT is generally superior to autopsy in the documentation and visualization of skeletal injuries [7]. MR on the other hand, is chiefly used to assess disease in cases of natural causes of death. This finding stands in agreement with the clinical applications of MR [24]. CT and MR were used in combination in a small minority of studies during the last decade. These results reflect the subjective impression of the authors regarding the current situation in forensic radiology; CT scanners have been installed in several forensic institutions across the world, and whole-body post-mortem CT prior to autopsy is becoming a routine examination [11]. Limited access to MR scanners, time constraints, and the complexity of MR technology are the most probable reasons why MR is used less frequently than CT in forensic investigations. Our findings indicate that this situation is different for non-forensic post-mortem research, where hospital MR scanners are more accessible and qualified personnel to perform and read MR scans available.

Table 4
Provenence of publications.

By region	n	%
All	661	100
Western Europe[a]	258	39
Northern Europe[b]	116	18
North America[c]	90	14
East Asia[d]	76	11
Southern Europe[e]	34	5
Eastern Europe[f]	29	4
Australia[g]	28	4
Middle East[h]	15	2
South Asia[i]	14	2
South America[j]	8	1
Africa[k]	3	0

[a] Austria, Belgium, France, Germany, Netherlands, Switzerland.
[b] Denmark, Finland, Ireland, Norway, Sweden, United Kingdom.
[c] Canada and USA.
[d] China, Japan, Korea, Mongolia, Thailand.
[e] Bosnia and Herzegowina, Croatia, Greece, Italy, Portugal, Spain.
[f] Czech Republic, Poland, Russia.
[g] Australia, New Zealand.
[h] Egypt, Israel, Saudi Arabia, Turkey.
[i] India, Pakistan.
[j] Argentina, Brazil, Chile.
[k] South Africa.

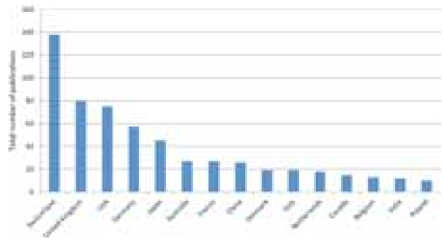

Fig. 4. Origin of publications by individual country. The five single countries with the highest number of publications are Switzerland (21%, $n=138/661$), UK (12%, 80/661), USA (11%, $n=75/661$), Germany (9%, $n=57/661$), and Japan (7%, $n=45/661$). Figure provides an overview of the 20 top ranking countries regarding the number of published articles on post-mortem and forensic radiology.

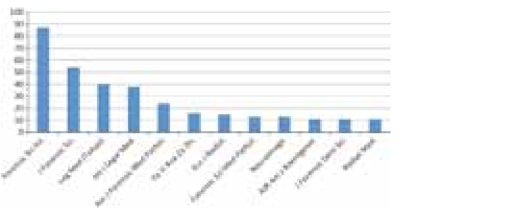

Fig. 5. Publishing journals. The 661 articles were published in 197 different peer-reviewed journals. Overall, 50% of all publications were published in the 12 journals only. Seven of these are dedicated to forensic medicine (including the Chinese Journal of Forensic Medicine), four to imaging, and one to forensic odontology.

Post-mortem CT-angiography (and rarely also MR-angiography) represents a validated method to document injuries of the vascular system [25–27]. However, our results indicate that angiography is rarely used in forensic practice. Despite the advantages provided by contrast enhanced CT and MR imaging, the additional cost and effort of angiography, as well as the apprehension that contrast media might negatively affect a subsequent autopsy are possible factors that prevent this method from being used more frequently. In addition, the number of publications on post-mortem angiography is still too small to scientifically support one or another technique or method. The results of our analysis suggest that the potential of post-mortem biopsy, photogrammetry and three-dimensional surface scanning is not yet fully appreciated in forensic investigations. As with MR, limited access, complexity, costs, and time constraints are main reasons why this technology is rarely used. Our study revealed that conventional radiographs are still widely used, notably in relation to identification of human remains either individually or in mass disaster situations. Ultrasound is chiefly used in non-forensic fetal studies, but only rarely in forensic post-mortem imaging [28,29]. The main reasons for this may be the subjectivity of the images, the (initial) complexity of creating and reading ultrasound images and the degradation of sonographic images by postmortem gas.

In this study we found that the vast majority of publications on forensic and post-mortem imaging discusses findings in cadavers of adult humans. Pediatric studies are more scarce and animal or model studies represent exceptions in post-mortem studies. It is important to note that the key words of this study were selected with an emphasis on post-mortem imaging. It is therefore understandable that a number of publications on imaging of child abuse in the living escaped our literature search. Ante-mortem studies aside, in our opinion research efforts in post-mortem pediatric radiology should be increased. In depth knowledge on non-traumatic and traumatic imaging findings in deceased children could add considerable value to post-mortem investigation of child abuse and may be useful to further improve the assessment of cases of suspected child abuse in living subjects.

Our study reveals that forensic radiology has become a global topic of research interest and there are considerable contributions from America, Australia, Asia, and Europe. In the last decade, Western and Northern Europe had the highest research output in this field. The ranking list of publications reflects both the financial means for research in forensic sciences as well as the recognition and adoption of forensic radiology within the forensic community. Currently, Switzerland leads the ranking list. The Virtopsy project was and still is an important promoter of forensic imaging in Switzerland and worldwide [13]. Our data indicates that Switzerland, Germany, the USA, Japan, and the UK were among the first countries to test the potential of cross-sectional imaging modalities in the post-mortem setting.

Overall, the majority of research in forensic and post-mortem imaging is published in journals devoted to forensic sciences and, to a lesser extent, radiology. The impact of these articles currently peaks at roughly three and six Impact Factor (IF) points when published in the leading journals in forensic sciences and radiology, respectively. Occasionally, high impact journals publish studies or reviews on the ongoing transition in forensic sciences. Currently the highest ranked article in the field was published by Roberts et al. in Lancet in 2011, with an impact of 38.287 IF points [30].

5. Limitations

Our study has several limitations that deserve comment. First, it may be argued that Medline and PubMed are not sufficient as the sole online databases for research. The authors agree that including additional databases for the search might have produced a larger n-size for analysis. However, PubMed represents an elementary source for research and the potential overlap between different archives would have hindered a timely evaluation of all 661 manuscripts. Second, it may be criticized that this analysis was based primarily on abstracts, rather than the full text. The authors agree that there would have been much more data to analyze. However, the goal of this study was to provide an overview of scientific publications in forensic and post-mortem imaging. Finally, it is important to note that as with any literature search, publications without any of our key words may have escaped our search, even if they were related to post-mortem and forensic imaging. However, we believe that the wide range of search terms used for this study was sufficient to capture the overwhelming majority of publications on post-mortem imaging. Nevertheless, the reader should bear in mind that our statistical analysis was based only on the 661 articles included in this study.

6. Conclusions

This study provides evidence that over the last decade, forensic and post-mortem radiology rose from an obscure topic to a relevant field in the forensic sciences. CT represents the preferred imaging modality in forensic imaging, and is chiefly used to document and visualize traumatic findings. MR is the favored imaging modality for non-forensic post-mortem imaging and is mainly used to detect non-traumatic findings. The primary research focus in forensic imaging is on traumatic findings, with a relative overrepresentation of studies regarding gunshot injuries. There are very few studies dedicated to imaging findings of drug abuse and intoxication, despite of their considerable contribution to the case load of forensic investigations. The growing body of peer-reviewed literature indicates that radiology is becoming an invaluable tool in post-mortem investigations, whether they are performed in the course of forensic investigation, or during hospital-based morbidity / mortality review. Research efforts in this field are conducted worldwide and forensic radiology may indeed qualify as a distinct subspecialty of forensic medicine and radiology.

References

[1] B.G. Brogdon, Forensic radiology in historical perspective, in: M.J. Thali, M. Viner, B.G. Brogdon (Eds.), Brogdon's Forensic Radiology, 2nd ed.,CRC Press, Boca Raton, 2010, pp. 3–7.
[2] B.G. Brogdon, Scope of forensic radiology, in: M.J. Thali, M.D. Viner, B.G. Brogdon (Eds.), Brogdon's Forensic Radiology, 2nd ed.,CRC Press, Boca Raton, 2010, pp. 25–39.
[3] R. Wüllenweber, V. Schneider, T. Grumme, A computer-tomographical examination of cranial bullet wounds (author's transl), [Article in German] Z Rechtsmed 80 (1977) 227–246.
[4] B.G. Brogdon, Preface, in: B.G. Brogdon (Ed.), Forensic radiology, 1st ed.,CRC Press LCC, Boca Raton, 1998.
[5] The Virtopsy Project. 〈www.virtpsy.com〉, 2012 (accessed 17.10.03).
[6] M.J. Thali, M. Braun, W. Brüschweiler, R. Dirnhofer, Matching tire tracks on the head using forensic photogrammetry, Forensic Science International 113 (2000) 281–287.
[7] M.J. Thali, K. Yen, W. Schweitzer, P. Vock, C. Boesch, C. Ozdoba, G. Schroth, M. Ith, M. Sonnenschein, T. Doernhoefer, E. Scheurer, T. Plattner, R. Dirnhofer, Virtopsy a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI)—a feasibility study, Journal of Forensic Sciences 48 (2003) 386–403.
[8] R.A. Bisset, N.B. Thomas, I.W. Turnbull, S. Lee, Postmortem examinations using magnetic resonance imaging: four year review of a working service, BMJ 324 (2002) 1423–1424.
[9] M.J. Thali, B.P. Kneubuehl, P. Vock, G. Allmen, R. Dirnhofer, High-speed documented experimental gunshot to a skull-brain model and radiologic virtual autopsy, American Journal of Forensic Medicine and Pathology 23 (2002) 223–228.
[10] C. O'Donnell, N. Woodford, Post-mortem radiology—A new sub-speciality? Clinical Radiology 63 (2008) 1189–1194.
[11] G.N. Rutty, B. Morgan, C. O'Donnell, P.M. Leth, M. Thali, Forensic institutes across the world place CT or MRI scanners or both into their mortuaries, Journal of Trauma 65 (2008) 493–494.
[12] B.G. Brogdon, H. Vogel, J.D.A. McDowell, Radiologic Atlas of Abuse, Torture, Terrorism, and Inflicted Trauma, 1st ed., CRC Press, Boca Raton, 2003.
[13] M.J. Thali, R. Dirnhofer, P. Vock, The Virtopsy Approach: 3D Optical and Radiological Scanning and Reconstruction in Forensic Medicine, 1st ed., CRC Press, Boca Raton, 2009.
[14] R.A.C. Bilo, S.G.F. Robben, R.R. van Rijn, Forensic Aspects of Pediatric Fractures: Differentiating Accidental Trauma from Child Abuse, 1st ed., Springer, Heidelberg, 2010.
[15] L.R. Folio, Combat Radiology: Diagnostic Imaging of Blast and Ballistic Injuries, 1st ed., Springer, New York, 2010.
[16] M.J. Thali, M.D. Viner, B.G. Brogdon, Brogdon's Forensic Radiology, 2nd ed., CRC Press, Boca Raton, 2010.
[17] A.D. Levy, T.H. Harcke, Essentials of Forensic Imaging: A Text-Atlas, 1st ed., CRC Press, Boa Raton, 2010.
[18] M.P. Burke, Forensic Pathology of Fractures and Mechanisms of Injury: Postmortem CT Scanning, 1st ed., CRC Press, Boca Raton, 2011.
[19] K.M. Stein, M.L. Bahner, J. Merkel, S. Ain, R. Mattern, Detection of gunshot residues in routine CTs, International Journal of Legal Medicine 114 (2000) 15–18.
[20] G.N. Rutty, P. Boyce, C.E. Robinson, A.J. Jeffery, B. Morgan, The role of computed tomography in terminal ballistic analysis, International Journal of Legal Medicine 122 (2008) 1–5.
[21] L.R. Folio, T. Fischer, P. Shogan, M. Frew, A. Dwyer, J.M. Provenzale, Blast and ballistic trajectories in combat casualties: a preliminary analysis using a cartesian positioning system with MDCT, AJR American Journal of Roentgenology 197 (2011) W233–W240.
[22] P.M. Leth, M. Worm-Leonhard, Tablet residues in stomach content found by routine post-mortem CT, Forensic Science International 179 (2008) e16–e17.
[23] M.P. Burke, C. O'Donnell, R. Bassed, The use of postmortem computed tomography in the diagnosis of intentional medication overdose, Forensic Science, Medicine and Pathology 8 (2012) 218–236.
[24] W.E. Brant, C.A. Helms (Eds.), Fundamentals of diagnostic radiology, 3rd ed.,Lippincott Williams & Wilkins, Philiadelphia, 2007.
[25] S. Grabherr, V. Djonov, K. Yen, M.J. Thali, R. Dirnhofer, Postmortem angiography: review of former and current methods, AJR American Journal of Roentgenology 188 (2007) 832–838.
[26] S.L. Saunders, B. Morgan, V. Raj, G.N. Rutty, Post-mortem computed tomography angiography: past, present and future, Forensic Science, Medicine and Pathology 7 (2011) 271–277.
[27] T.D. Ruder, G.M. Hatch, L.C. Ebert, P.M. Flach, S. Ross, G. Ampanozi, M.J. Thali, Whole body postmortem magnetic resonance angiography, Journal of Forensic Sciences 57 (2012) 778–782.
[28] J. Fariña, C. Millana, M.J. Fdez-Aceñero, V. Furió, P. Aragoncillo, V.G. Martín, J. Buencuerpo, Ultrasonographic autopsy (echopsy): a new autopsy technique, Virchows Archiv 440 (2002) 635–639.
[29] S. Uchigasaki, L. Oesterhelweg, A. Gehl, J.P. Sperhake, K. Püschel, S. Oshida, N. Nemoto, Application of compact ultrasound imaging device to postmortem diagnosis, Forensic Science International 140 (2004) 33–41.
[30] I.S. Roberts, R.E. Benamore, E.W. Benbow, S.H. Lee, J.N. Harris, A. Jackson, S. Mallett, T. Patankar, C. Peebles, C. Roobottom, Z.C. Traill, Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study, Lancet 379 (2012) 136–142.

0022-5282/94/3704-0552$03.00/0
THE JOURNAL OF TRAUMA
Vol. 37, No. 4

UTILITY OF POSTMORTEM COMPUTED TOMOGRAPHY IN TRAUMA VICTIMS

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A possible way to circumvent the continuing decline in the number of autopsies is to perform computed tomography after death. The present study compares the pathologic findings of postmortem CT tomography (PMCT) in trauma fatalities with those disclosed upon conventional forensic autopsy. Within 6 hours of death, the bodies of 25 trauma victims underwent total body CT scanning, all with permission of the relatives, followed by conventional autopsy in 13 cases under court order. The pathologist and roentgenologist were unaware of each other's findings. The pathologic findings of PMCT plus conventional autopsy provided more information than either examination alone. Of the total 127 pathologic findings, 44.9% were diagnosed by both conventional autopsy and PMCT, 29.9% were not revealed by PMCT, whereas conventional autopsy missed 25.2%, and PMCT detected more bone injuries than did autopsy, whereas the latter was superior to PMCT in discovering soft-tissue pathologic states. In all, PMCT revealed 70.5% and autopsy 74.8% of the pathologic states. Although PMCT was not more effective than conventional autopsy in exposing pathologic entities, it increased the yield of findings when combined with conventional autopsy. Where conventional autopsy is unattainable, PMCT may be effective in shedding light on the pathologic state and mechanism of death in trauma fatalities.

POSTMORTEM (PM) examination is still one of the finest tools for quality assessment and evaluation of medical diagnosis and treatment, and it is therefore more than regrettable that the number of autopsies carried out world wide is steadily declining. The principal reasons for this unwelcome trend are the added burden to the routine surgical and clinical obligations of the pathologist,[1] and ethical-religious considerations. Thus, for instance, the Jewish religion stipulates that burial take place within several hours of death, and prohibits any interference with the body, so as to preserve the dignity of the deceased.[2] Most Jewish families therefore withhold their permission for an autopsy, and many religious Moslem and Christian families are also very reluctant to agree to a PM examination of a next of kin.

Notwithstanding the deep-seated opposition of many individuals to autopsies, these examinations cannot always be avoided. There may be legal necessities for performing postmortem examination after criminal acts or deaths of unknown cause or as a result of accidents. In short, for evaluation of trauma and effective assessment of trauma care the course of diminishing autopsy activity should be reversed, giving us the opportunity to learn to distinguish between preventable and nonpreventable deaths.

A potential mechanism for obtaining vital postmortem information without hurting the feelings of the next of kin or infringing upon religious edict is to conduct postmortem computed tomography (PMCT) of the body. If the PMCT is performed shortly after death, visualization of the brain and skeleton may provide useful clues, which could help disclose the ultimate cause of death.

To determine whether PMCT has practical value, some salient questions must be answered: What is the specificity of PMCT compared with conventional autopsy? Are the results of a CT scan reliable, provided it is performed within 6 hours of death?

METHODS

The present study was carried out at Hadassah Hebrew University Hospital in Jerusalem. The research project was submitted to the Human Use ("Helsinki") Committee of the hospital. Since, however, the study did not involve live patients, the Committee decided that this subject did not come under its jurisdiction. The problem was then presented to the hospital authorities, who allowed implementation of the study, provided verbal consent was obtained from the next of

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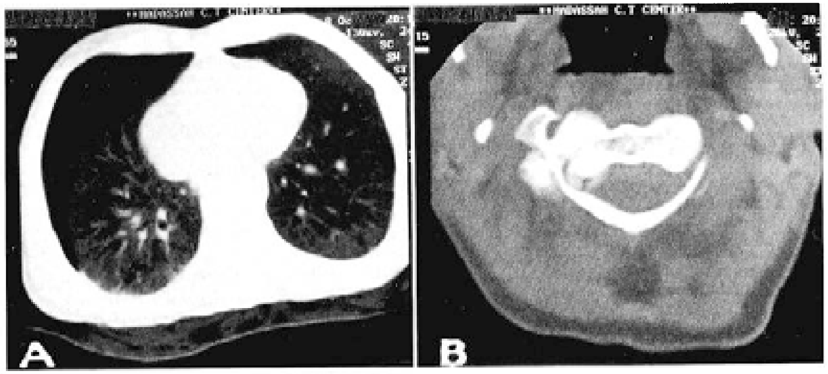

Figure 1 Postmortem computed tomographic scan carried out 6 hours after death. (A) Obvious right and small left pneumothorax; (B) comminuted fracture of C-2.

kin in each case. Included in the study were murder victims, trauma patients who were dead on arrival at the hospital, and trauma patients who died during resuscitation attempts. In all cases the CT examination was carried out within 6 hours of death. The procedure was performed in the Radiology Department of the hospital, the use of the CT equipment for the purpose of this investigation also having been approved by the hospital authorities. Most families categorically refused permission for a conventional autopsy, but none objected to a CT scan of the deceased. All CT examinations were carried out with an EXEL 2400 or an ELITE 2400 scanner (Elscint, Israel). Slice width was 10 mm with 10-mm increments, except in the neck and posterior fossa, where the increments were 2.5 to 5.0 mm. Strength of irradiation was 130 kV, scanning time was 1–2 seconds, and irradiation intensity was 252–315 mAS.

Immediately after scanning, the bodies to which a court order for conventional autopsy was attached were transferred to the Institute of Forensic Pathology in Tel Aviv. The attending pathologist was unaware of the results of the PMCT, and the radiologist was not informed of the autopsy findings. A "finding" was defined as a pathologic state in one organ, e.g., fracture of one or more ribs was registered as one finding. The results of the forensic pathology study were compared with the radiologic findings.

RESULTS

The current study covered the period January through December 1992. During this time, CT scans and conventional autopsies were carried out on 13 patients, whereas in 12 other cases CT scanning was not followed by conventional autopsy because no court order had been issued in these instances. Figure 1 shows the PMCT scan of a road traffic victim who died suddenly within 2 hours of his arrival at the emergency ward. Because permission for conventional PM examination was withheld by the family, a total body PMCT was carried out. The scan, performed 6 hours after death, showed bilateral pneumothorax (Fig. 1A) and multiple skeletal abnormalities, among which was discerned a comminuted fracture of C-2 (Fig. 1B); the ensuing swelling within the spinal canal was presumed the immediate cause of death. The roentgenograms performed upon the patient's arrival in the emergency ward failed to demonstrate either the pneumothorax or the C-2 fracture.

Table 1 provides two representative examples of PMCT results and autopsy findings; the cases in question concerned the remains of a young male adult who committed suicide by jumping from a tall building, and those of a young male in whom the mechanism of injury was a blast following accidental bomb explosion. Some of the injuries visualized by the CT scan were not observed during conventional autopsy, some other pathologic findings were not detected on the CT scan by the radiologist.

Analysis of the total 127 findings in the 13 cases in which both autopsy and PMCT were carried out, grouped according to the tissues involved, demonstrated PMCT to be complementary to autopsy (Table 2).[3] Thus the combined PMCT plus conventional autopsy procedure uncovered 57 (44.9%) pathologic findings. Thirty-two (25.2%) PMCT findings, including air in body cavities, were not discovered on conventional autopsy, whereas the latter revealed 38 (29.9%) pathologic entities not visualized on scanning.

DISCUSSION

To the best of our knowledge this is the first study that compares the results of total body postmortem CT scanning with the findings of conventional autopsies. In fact, PMCT is not utilized frequently and is scarcely mentioned in the literature. The few articles that do

Table 1
Comparison between postmortem computed tomography visualization results and autopsy findings in two cases

Postmortem CT Scanning	Conventional Autopsy
a) Suicide by jumping from building	
Fracture of foramen magnum	Same
Fracture of mandible	Same
Fracture of C-7	Not detected
Bone fragments in spinal canal	Not detected
Fracture of transverse process C-6	Not detected
Bilateral rib fractures	Same
Bilateral fracture of scapula	Not detected
Bilateral haemopneumothorax	Same
Air in cardiac ventricles	Not detected
Perirenal hemorrhage	Same
Multiple pelvic fractures	Same
Not visualized	Complete rupture of lung hilum
Not visualized	Pericardial tear
Not visualized	Rupture of heart
Seen but not quantified	600 mL blood in abdominal cavity
Not visualized	Ruptured spleen and liver
b) Blast injuries	
Foreign bodies in right orbit and frontal lobes	Same
Fracture in base of skull near right orbit	Same
Fractures in frontal bones	Same
Pneumocephalus	Not detected
Not visualized	Small intraventricular hemorrhage
Foreign body in soft tissue of neck	Small stone in subcutaneous neck tissue
Multiple foreign bodies in subcutaneous tissue of chest	Not detected
Opacities at right lower lung base	Hemorrhage at right lower lung base
Not visualized	Fractured rib
Abdominal wall tear with eventration of intestine	Same
Large metal fragment in anterior abdominal wall	Same
Air in peritoneum	Not detected
Empty stomach	Same

Table 2
Distribution of findings according to postmortem procedure

Tissue	Computed Tomography	Conventional Autopsy	Computed Tomography – Conventional Autopsy	Total Number of Findings
Bone	10 (25.3)*	9 (22.5)	21 (52.5)	40
Soft tissue	14 (23.3)	19 (31.6)	27 (45.0)	60
Hollow viscus	8 (29.6)	10 (37.0)	9 (33.3)	27
Total	32 (25.2)	38 (29.9)	57 (44.9)	127 (100)

* Numbers in parentheses constitute the percentage of the total number of findings in the relevant tissues.

address this mode of forensic examination mainly discuss its use in isolated organ preparations.[3–8] We found one case report of PMCT after a diving accident in which the distribution of gas bubbles in the brain was noted.[9] Another article reports good agreement between CT findings and cross-sectional pathologic changes in the brains of 24 victims of gunshot wounds to the head.[10]

A logical explanation for the scant attention paid to PMCT is that few radiology departments can afford to "squander" precious time on examination of a deceased person. In addition, they do not have the facilities for bringing dead bodies onto their premises by discreet means. But these are, after all, practical—and, admittedly, also financial—difficulties that should not stand in the way of a method that will help teach us to recognize preventable deaths.

This study shows that PMCT in conjunction with conventional PM examination reveals more details than either method by itself. Furthermore, injuries that were visualized by the CT scanning were not detected by the conventional PM examination, implying that autopsies are not the "gold standard" by which to evaluate PMCT. To further elucidate the lack of conformity between autopsy and PMCT, we compared the findings obtained in the three procedures PMCT, conventional autopsy, and PMCT plus autopsy.

It appeared that PMCT disclosed 70.1% of the 127 findings, whereas conventional autopsy revealed 74.8% of the pathologic entities. Since the results do not diverge greatly, it seems to us that PMCT may have a place in the detection and evaluation of the cause or causes of death. Another valuable fact that came to light was that the CT scan was able to demonstrate air in body cavities. Forensic reports rarely mention such findings, since it is technically complicated to detect air pockets on conventional PM. Because all CT examinations were performed within 6 hours of death, there were no signs of putrefaction, affording clear visualization of the scan findings.[11]

Our advocacy of PMCT is based on the following: it is a rapid test, taking approximately 20 minutes from start to finish; the scanning procedure itself is carried out by a technician to be interpreted by the radiologist at a later time; there is no need for direct contact with the remains—some of the scans were even performed with the corpse still in the body bag—rendering nil the risk of, for example, HIV infection that is possible during conventional autopsy; the printed output provided by CT scanning is realistic and durable evidence of the injuries, which might prove a decisive factor in court cases; the three-dimensional reconstruction may assist in identifying the murder weapon in homicide cases in which this factor is obscure; and last but not least, since PMCT does not affect the body, families seldom or never raise objections to the procedure on religious, moral, or esthetic grounds. Furthermore, the cost (to

the hospital) of a PMCT is less than $700 for a total body scan, whereas the cost of a PM examination, with all the laboratory workup, may be more than $1500.

The unexpected spinoff of this evaluation of PMCT, which was motivated purely by the dearth of conventional autopsies, is the indication that PMCT may very well serve as an adjunct to conventional autopsy, and may prove valuable in instances where permission to carry out the latter is withheld. Admittedly, it is doubtful whether PMCT can wholly replace conventional autopsy, but even if performed as the sole PM examination, it may shed light on the cause of death in trauma patients and may elucidate whether death could have been prevented, as clearly illustrated in the herein quoted case.

REFERENCES

1. Riboli E, Delendi M (eds): *Autopsy in Epidemiology and Research*. Lyon, IARC Scientific Publication No. 112, 1991
2. Deuteronomy 21:23
3. Grafton ST, Sumi SM, Stimac GK, et al: Comparison of postmortem magnetic resonance imaging and neuropathologic findings in the cerebral white matter. *Arch Neurol* 48:293, 1991
4. Tanimoto K, Petersson A, Rohlin M, et al: Comparison of computed with conventional tomography in the evaluation of temporomandibular joint disease: A study of autopsy specimens. *Dentomaxillofac Radiol* 19:21, 1990
5. Carson SC, Hertzberg BS, Bowie JD, et al: Value of sonography in the diagnosis of intracranial hemorrhage and periventricular leukomalacia: A postmortem study of 35 cases. *AJNR* 11: 677, 1990
6. Singer KP, Breidahl PD: Vertebral body trabecular density at the thoracolumbar junction using quantitative computed tomography. *Acta Radiol* 31:37, 1990
7. Tanimoto K, Hansson LG, Petersson A, et al: Computed tomography versus single-contrast arthrotomography in evaluation of the temporomandibular joint disc: A study of autopsy specimens. *Int J Oral Maxillofac Surg* 18:354, 1989
8. Quint LE, Glazer GM, Orringer MB, et al: Mediastinal lymph node detection and sizing at CT and autopsy. *AJR* 147:469, 1986
9. Kranz P, Holtas S: Postmortem computed tomography in a diving fatality. *J Comput Assist Tomogr* 7:132, 1983
10. Schumacher M, Oehmichen M, Konig HG, et al: Intravital and postmortal CT examinations in cerebral gunshot injuries. *ROFO Forthschr Geb Roentgenstr Nuklearmed* 139:58, 1983
11. Coe JI, Curran WJ: Definition and time of death. In Curran WJ, McGarry AL, Petty CS (eds): *Modern Legal Medicine, Psychiatry and Forensic Science*. Philadelphia, F.A. Davis, 1980, pp 159–160

DISCUSSION

Dr. Sheryl G. A. Gabram (Hartford, Connecticut): To autopsy or not to autopsy is essentially the question that is raised by Doctor Rivkind and colleagues in this prospective study of 12 patients who underwent postmortem CT examination (PMCT) before conventional autopsy.

The real question raised by the authors is the ability of postmortem CT to measure up to the gold standard, autopsy. The potential role of PMCT is particularly relevant to the authors' institution largely because of the Jewish religious beliefs that advocate maintaining the integrity of the body and returning it to the ground in a timely fashion.

To better understand this autopsy/no autopsy debate, one should be acquainted with the evolving purposes of the autopsy over the past several centuries. Hippocrates was of the opinion that an autopsy was "an unpleasant, if not cruel, task" (Landefeld GS, Goldman L: The autopsy and quality assurance, history, current status, and future direction. *Quad Rev Bull* 15; 42, 1989). The early prime purposes of anatomic investigation and ceremonial religious reasons have been replaced by more contemporary purposes such as cataloguing of human clinical and anatomic disease, medical education and continuing education, and quality assessment of medical care (Hill RB, Anderson RE: The evolving purposes of the autopsy: 21st century values from an 18th century procedure. *Perspect Biol Med.* 32: 223, 1989). The higher purpose of autopsies in benefiting society as it relates to public health care policy and resource allocation is particularly relevant.

The fact remains, however, that autopsy rates have fallen from about 50% in the 1940s to 10% to 15% today. The reasons for this declining rate include advancements in technology providing better clinical knowledge before the demise of the patient, physicians not dedicating enough time to encourage families of the need for an autopsy, the lack of data demonstrating quality improvement in medical care as a result of an autopsy review, and financial realities where a state medical examiner's office may need to prioritize requested autopsies. These realities may pave the way to consider other modalities aside from the autopsy to obtain clinical pathologic correlation.

Although the authors have identified that PMCT and conventional autopsy yield findings in 70% and 74% of cases, respectively, the key issue is the ability to diagnose what really killed the patient and not the numerous associated nonrelevant findings.

A companion report published in the journal *Magnetic Resonance Imaging* (Ros PR, Lik C, Baer H, et al: Preautopsy magnetic resonance imaging: Initial experience. *Magn Reson Imaging* 8: 303, 1990) in 1990 by a group from the University of Florida in Gainesville addressed the role of pre-autopsy magnetic resonance imaging. The authors concluded that MRI was equal to autopsy in detecting gross cranial, pulmonary, abdominal, and vascular pathology in a small series of six patients. Like CT scanning, the MRI was found to be superior to autopsy in detecting air and fluid in potential body spaces. However, neither this nor the current report answer the key question.

I would further argue the replacing autopsies with CT scans has absolutely no cost-saving potential. Many pathologists argue that the external examination of the body is an essential component of the autopsy and would still need to be performed, thus generating a pathologist review and report even in the setting of CT examination.

The cost of maintaining CT scan equipment in ME offices across the country, or, if the acute care hospital is utilized, the charges to the deceased's family for a total body scan may be quite high, notwithstanding, as we heard this morning, the cost of the obligatory radiologic interpretation. In a cost-conscious society, replacing autopsies with CT scanning provides no apparent advantages.

This leaves the final argument of religious considerations. In the State of Connecticut, with a population of 3.6 million and approximately 1400 autopsies performed on an annual basis at the state ME's office, the chief medical examiner stated to me that significant religious concerns occur once in about every 2 years. If the medical examiner is willing to meet with the deceased patient's family, explaining the importance and reasons for the autopsy, offering to solicit, in this case, the rabbi's permission and, if necessary, presence of the rabbi at the autopsy, the vast majority of these cases can be resolved. This strategy, however, requires a very compassionate, caring, and communicative pathologist.

In summary, I have two questions for the authors:

1. Please comment on the generation of CT scanners, the XL-2400 or the Elite 2400 utilized in your study, especially in light of the single patient listed in Table 1 of the manuscript in whom a ruptured liver and spleen was not detected on the CT scan.

2. In how many cases was the primary cause of death detected in PMCT versus conventional autopsy?

Thank you.

Dr. Avraham I. Rivkind (Closing): I would like to thank Doctor Gabram for her comments and remarks. I wish I were working in Connecticut and not in Israel because in Israel the pathologists are not as tolerant and polite as you have described them in your state. In addition, the families of the deceased in Israel are less autopsy minded, mainly for religious reasons. Therefore it is very difficult to achieve PMs in Israel. But we are doing our best.

In any case, to answer your questions, the case of the Israel Air Force pilot who ejected himself from the cockpit of an F-15 demonstrates the unique usage of CT as a diagnostic PM tool. The PMCT revealed a commuted fracture of C-2, fracture of the odontoid process, epidural hematoma, and spinal cord compression. These findings explained the cause of death. In the other cases, the PMCT was complementary by 70% to 75% to conventional autopsies.

Thank you.

The Medicolegal Death Investigation System

Although steps have been taken to transform the medicolegal death investigation system, the shortage of resources and lack of consistent educational and training requirements (particularly in the coroner system)[26] prevent the system from taking full advantage of tools—such as CT scans and digital X-rays—that the medical system and other scientific disciplines have to offer. In addition, more rigorous efforts are needed in the areas of accreditation and adherence to standards. Currently, requirements for practitioners vary from nothing more than age and residency requirements to certification by the American Board of Pathology in forensic pathology.

Funds are needed to assess the medicolegal death investigation system to determine its status and needs, using as a benchmark the current requirements of NAME relating to professional credentials, standards, and accreditation. And funds are needed to modernize and improve the medicolegal death investigation system. As it now stands, medical examiners and coroners (ME/Cs) are essentially ineligible for direct federal funding and grants from DOJ, DHS, or the Department of Health and Human Services (through the National Institutes of Health). The Paul Coverdell National Forensic Science Improvement Act is the only federal grant program that names medical examiners and coroners as eligible for grants. However, ME/Cs must compete with public safety agencies for Coverdell grants; as a result, the funds available to ME/Cs are inadequate. The simple reality is that the program has not been sufficiently funded to provide significant improvements in ME/C systems.

In addition to direct funding, there are other initiatives that should be pursued to improve the medicolegal death investigation system. The Association of American Medical Colleges and other appropriate professional organizations should organize collaborative activities in education, training, and research to strengthen the relationship between the medical examiner community and its counterparts in the larger academic medical community. Medical examiner offices with training programs affiliated with medical schools should be eligible to compete for funds. Funding should be available to support pathologists seeking forensic fellowships. In addition, forensic pathology fellows could be allowed to apply for medical school loan forgiveness if they stay full time at a medical examiner's office for a reasonable period of time.

Additionally, NIFS should seek funding from Congress to support the joint development of programs to include medical examiners and medical examiner offices in national disaster planning, preparedness, and consequence management, involving the Centers for Disease Control and Prevention (CDC) and DHS. Uniform statewide and interstate standards of operation would be needed to assist in the management of cross-jurisdictional and interstate events. NIFS should support a federal program underwriting the development of software for use by ME/C systems for the management of multisite, multiple fatality events.

NIFS should work with groups such as the National Conference of Commissioners on Uniform State Laws, the American Law Institute, and NAME, in collaboration with other appropriate professional groups, to update the 1954 Model Post-Mortem Examinations Act and draft legislation for a modern model death investigation code. An improved code might, for example, include the elements of a competent medical death investigation system and clarify the jurisdiction of the medical examiner with respect to organ donation.

The foregoing ideas must be developed further before any concrete plans can be pursued. There are, however, a number of specific recommendations, which, if adopted, will help to modernize and improve the medicolegal death investigation system. These recommendations deserve the immediate attention of Congress and NIFS.

[26] Institute of Medicine. 2003. *Workshop on the Medicolegal Death Investigation System*. Washington, DC: National Academies Press.

Recommendation 11:

To improve medicolegal death investigation:

(a) Congress should authorize and appropriate incentive funds to the National Institute of Forensic Science (NIFS) for allocation to states and jurisdictions to establish medical examiner systems, with the goal of replacing and eventually eliminating existing coroner systems. Funds are needed to build regional medical examiner offices, secure necessary equipment, improve administration, and ensure the education, training, and staffing of medical examiner offices. Funding could also be used to help current medical examiner systems modernize their facilities to meet current Centers for Disease Control and Prevention-recommended autopsy safety requirements.

(b) Congress should appropriate resources to the National Institutes of Health (NIH) and NIFS, jointly, to support research, education, and training in forensic pathology. NIH, with NIFS participation, or NIFS in collaboration with content experts, should establish a study section to establish goals, to review and evaluate proposals in these areas, and to allocate funding for collaborative research to be conducted by medical examiner offices and medical universities. In addition, funding, in the form of medical student loan forgiveness and/or fellowship support, should be made available to pathology residents who choose forensic pathology as their specialty.

(c) NIFS, in collaboration with NIH, the National Association of Medical Examiners, the American Board of Medicolegal Death Investigators, and other appropriate professional organizations, should establish a Scientific Working Group (SWG) for forensic pathology and medicolegal death investigation. The SWG should develop and promote standards for best practices, administration, staffing, education, training, and continuing education for competent death scene investigation and postmortem examinations. Best practices should include the utilization of new technologies such as laboratory testing for the molecular basis of diseases and the implementation of specialized imaging techniques.

(d) All medical examiner offices should be accredited pursuant to NIFS-endorsed standards within a timeframe to be established by NIFS.

(e) All federal funding should be restricted to accredited offices that meet NIFS-endorsed standards or that demonstrate significant and measurable progress in achieving accreditation within prescribed deadlines.

(f) All medicolegal autopsies should be performed or supervised by a board certified forensic pathologist. This requirement should take effect within a timeframe to be established by NIFS, following consultation with governing state institutions.

AFIS and Database Interoperability

Great improvement is necessary in AFIS interoperability. Crimes may go unsolved today simply because it is not possible for investigating agencies to search across all the databases that might hold a suspect's fingerprints or that may contain a match for an unidentified latent print from a

NZZ.CH
Neue Zürcher Zeitung

18. April 2012, 06:00

Sezieren ohne Skalpell

Neuartige 3-D-Software ermöglicht virtuelle Anatomiepräparate und Autopsien

18. April 2012, 06:00

Studierende der New York University School of Medicine im 3-D-Anatomiekurs. (Bild: PD)

An der New York University sezieren Studenten Leichen, ohne ein Skalpell anzulegen. Möglich macht das eine neue Software, die die Darstellung und das Anfertigen von Querschnitten und Präparaten erlaubt.

Martin Angler

Das Sezieren von Leichen und Herauspräparieren von Organen ist in den meisten Ländern ein wesentlicher Bestandteil des Medizinstudiums. Angehende Mediziner lernen in diesen Präparierkursen die menschliche Anatomie aus erster Hand – so auch am New York University Langone Medical Center. Dort findet jedoch im Zimmer neben dem klassischen Autopsieraum ein ganz spezieller Anatomiekurs statt. Die Studenten tragen statt eines Arztkittels eine 3-D-Brille, verwenden statt eines Autopsietischs eine Projektionsleinwand und sezieren statt mit einem Skalpell mit der Computermaus: Die Leiche, die sie unter der Aufsicht von John Qualter, einem Assistenzprofessor für Bildungsinformatik, untersuchen, ist nicht echt, sondern ein auf die Leinwand projiziertes 3-D-Modell.

Anatomische Strukturen

Entwickelt hat das Modell die Firma BioDigital, die eng mit der New Yorker Universität zusammenarbeitet. Im Unterricht rufen die Studenten einfach die Website www.biodigitalhuman.com auf, die ein 3-D-Modell eines menschlichen Körpers bereithält – mit zu- und abschaltbaren anatomischen Strukturen. Nach dem Öffnen der Seite entscheiden sich die Studenten zunächst für das Geschlecht des virtuellen Leichnams. Dann wählen sie per Mausklick die anzuzeigenden anatomischen Strukturen aus, etwa Knochenstruktur, Muskelgruppen oder Nervenbahnen. Damit können sie beispielsweise nur die Knochen und Muskeln einer Hand anzeigen und diese beliebig drehen, heranzoomen und so im Detail betrachten. Bei Bedarf stellt die Website das 3-D-Modell auch in einer Röntgenansicht dar. Damit das Erlebnis realistischer wirkt, tragen die angehenden Mediziner 3-D-Brillen.

Neben der reinen Anzeige des Körpers können die Studenten die virtuelle Leiche auch sezieren, wie Qualter sagt. Mit der Maus markieren sie dafür einzelne Körperteile und isolieren diese vom Rest des Körpers. Querschnitte erstellen sie mithilfe einer virtuellen Ebene, die sie wie ein Blatt Papier durch die Leiche schieben. Dies funktioniert mit dem gesamten 3-D-Modell oder mit einzelnen, isolierten Organen. Haben die Studenten ein Organ markiert, gibt die Software auch gleich Hinweise auf häufige Erkrankungen und bietet Links auf weiterführende Literatur an. «BioDigital Human» hilft den Studenten ausserdem über eine Sprachausgabe beim korrekten Benennen der sezierten Teile.

Das Internet-Tool im Anatomieunterricht einzusetzen, habe viele Vorteilen, sagt Qualter. So sei der Konservierungszustand der virtuellen Leichen im Gegensatz zu den realen Pendants optimal; echte Leichen hingegen seien oftmals anatomisch unvollständig, etwa nach dem Entfernen des Blinddarms oder einer Niere zu Lebzeiten. Des Weiteren könnten die Studenten auch ausserhalb des Hörsaals weiter sezieren und die menschliche Anatomie erkunden, so Qualter.

Fehlende haptische Eindrücke

Trotz all dieser Vorteile hat die neue Unterrichtsmethode aber auch einen gravierenden Nachteil: Die Studierenden können beim virtuellen Sezieren die menschliche Anatomie nicht erfühlen, wie Qualter betont. Das sei gerade als Vorbereitung auf spätere Operationen ein Nachteil. Wegen des fehlenden haptischen Erlebnisses sei «BioDigital Human» kein Ersatz für die klassische Autopsie, sondern allenfalls eine Ergänzung, sagt Qualter. Die neue Unterrichtsmethode sei als interaktives Anatomiebuch zu verstehen oder als eine Art Google-Maps des menschlichen Körpers.

Ein Einsatzgebiet für die neue Unterrichtsmethode könnten Länder wie Italien sein, wo Präparierkurse im Lehrplan fehlen. Die Ärztin Irene Esposito, die in Pisa studiert hat und heute als Pathologin in München arbeitet, sieht jedenfalls keine Nachteile wegen der fehlenden praktischen Anatomiekurse. Durch geeignete Lektüre und viel Einsatz könnten die Studenten dasselbe Wissen erlangen, ist sie überzeugt. Systeme wie «BioDigital Human» seien zudem nicht nur als Kompensation für fehlende Präparierkurse begrüssenswert, sondern für alle angehenden Mediziner, sagt Esposito.

«Virtopsy» in der Schweiz

Ansätze wie «BioDigital Human» werden auch ausserhalb von Amerika verfolgt. In der Schweiz etwa gibt es seit mehr als zehn Jahren das Projekt «Virtopsy», das an den Universitäten Zürich und Bern entwickelt wird. Unter der Leitung von Michael Thali vom Institut für Rechtsmedizin der Universität Zürich untersuchen Ärzte mit bildgebenden Messverfahren Leichen. Sie führen also Autopsien durch, ohne die Leichen zu öffnen. Dazu erstellen sie zuerst mit einem Laserscanner ein äusseres 3-D-Modell des Opfers und speichern es im Computer. Dem Laser entgeht dabei nicht die kleinste Oberflächenveränderung des Körpers: Schuss- und Stichwunden etwa können leicht erkannt und vermessen werden.

Als Nächstes kommt die Leiche in einen Computertomografen, der eine Serie von Querschnitten des Körpers anfertigt und diese – ebenfalls als Modell – speichert. Die Rechtsmediziner untersuchen schliesslich die erstellten Modelle am Rechner und können so die Todesursache von Unfall- oder Mordopfern feststellen. Die Methode geht heute so weit, dass an Unfällen beteiligte Fahrzeuge mit mobilen Laserscannern vermessen, als Modell gespeichert und ins forensische Labor gebracht werden.

Die Modelle der Leichen und der Unfallfahrzeuge werden am Rechner millimetergenau ineinandergepasst. Auf diese Weise können die Forensiker nicht nur die Todesursache, sondern auch den genauen Unfallhergang rekonstruieren. Habe man die Leichen erst einmal vermessen und gespeichert, sagt Thali, könne man jederzeit darauf zurückgreifen und sie neu untersuchen. Bei klassischen Autopsien müssten bereits sezierte und bestattete Leichen hingegen für Nachuntersuchungen exhumiert werden. Noch ist allerdings «Virtopsy» als alleiniges Beweismittel vor Gericht nicht zugelassen, wie Thali betont.

Keine Zerstörung des Körpers

Ansätze wie «BioDigital Human» und «Virtopsy» läuten zweifellos eine neue Ära in der Untersuchung von menschlichen Körpern ein. Obwohl in unterschiedlichen Bereichen eingesetzt, lösen sie das gleiche, zentrale Problem: Bei der konventionellen Autopsie werden die Leichen unwiederbringlich verändert, das heisst, sie können nie mehr in den Originalzustand zurückversetzt werden. Bei der virtuellen Autopsie genügt zu diesem Zweck ein Mausklick. Damit dürften auch Pannen wie jene an der Universität Köln vermieden werden: Deren anatomisches Institut hatte, wie im Februar bekanntwurde, über Monate Dutzende von Leichen ungenutzt gelagert, statt sie zur Bestattung freizugeben.

Clinical Anatomy 27:556–562 (2014)

ORIGINAL COMMUNICATION

Postmortem Circulation: A New Model for Testing Endovascular Devices and Training Clinicians in Their Use

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The development of new medical devices, such as aortic valves, requires numerous preliminary studies on animals and training of personnel on cadavers before the devices can be used in patients. Postmortem circulation, a technique used for postmortem angiography, allows the vascular system to be reperfused in a way similar to that in living persons. This technique is used for postmortem investigations to visualize the human vascular system and to make vascular diagnoses. Specific material for reperfusing a human body was developed recently. Our aim was to investigate whether postmortem circulation that imitates in vivo conditions allows for the testing of medical materials on cadavers. We did this by delivering an aortic valve using minimally invasive methods. Postmortem circulation was established in eight corpses to recreate an environment as close as possible to in vivo conditions. Mobile fluoroscopy and a percutaneous catheterization technique were used to deliver the material to the correct place. Once the valve was implanted, the heart and primary vessels were extracted to confirm its position. Postmortem circulation proved to be essential in several of the cadavers because it helped the clinicians to deliver the material and improve their implantation techniques. Due to the intravascular circulation, sites with substantial arteriosclerotic stenosis could be bypassed, which would have been impossible without perfusion. Although originally developed for postmortem investigations, this reperfusion technique could be useful for testing new medical devices intended for living patients. Clin. Anat. 27:556–562, 2014.

Key words: postmortem perfusion; clinical anatomy; aortic valve; surgical training

INTRODUCTION

The development of transcatheter technology and, more specifically, transcatheter aortic valves requires the preclinical use of animal models to study the performance of the implant in acute and chronic situations. Unfortunately, there are fundamental

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Received 12 June 2013; Revised 28 October 2013; Accepted 1 November 2013

Published online 21 December 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ca.22357

anatomical differences between animal models and humans. None of the current animal models allow for adequate evaluation of the position, deployment, anchoring, and functioning of transcatheter aortic heart valves in the orthotopic position. The main limitations of these models are the short distance between the ostia of the coronary arteries and the aortic valve annulus, the small distance between the aortic valve annulus and the mitral valve leaflets (absence of an aortic–mitral hinge), the relatively short length of the ascending aorta, and the angle of the aortic arch curvature (Serruys et al., 2010). In addition to these anatomical differences, the absence of calcification, which characterizes severe calcific aortic stenosis, makes the model inappropriate for evaluating and assessing the fixation and migration (anchoring) behavior of the implant.

To overcome these anatomical and etiological limitations, a more appropriate model is needed. Human cadavers have been used to study the placement of endovascular devices and to assess how they might interact with the local anatomy. The use of cadavers for this purpose has been limited because it was only possible by means of surgical access, which limits the relevance of the findings to the performance of devices normally placed by endovascular delivery. Therefore, the advent of a new technology that allows endovascular procedures to be performed on human cadavers would be of great benefit to researchers.

In 2008, Grabherr et al. introduced a modified heart–lung machine that establishes postmortem circulation and allows for injection of a contrast agent and the constant perfusion of cadavers. This technique was established for postmortem angiography to diagnose vascular lesions that could explain the cause of death, and it has been further developed and standardized. Recently, multiphase postmortem computed tomography angiography (MPMCTA; Grabherr et al., 2011) was introduced as a routine technique in several institutes of legal medicine. The aim of this study was to adapt the system developed for MPMCTA to establish postmortem circulation in human cadavers; our hypothesis was that this would facilitate endovascular procedures.

MATERIALS AND METHODS

Subjects

The present study was performed on eight human bodies (six men and two women) donated by an anatomical institute. To preserve the anonymity of the donors, information such as medical history was not disclosed. All the donors were between 65 and 100 years old at the time of death. The study took place in the anatomy department of Freiburg University, Switzerland, in three sessions between August 2010 and November 2011. The specimens were prepared according to the Thiel cadaver embalming technique (Thiel, 2002).

Postmortem computed tomography

Four of the eight bodies underwent postmortem computed tomography (PMCT) to detect calcification of the aortic valves. The examinations were performed with an eight-row computed tomography (CT) unit (CT LightSpeed 8; GE Healthcare, Milwaukee, WI) with the following scan parameters: field of view, 50 cm; slice thickness, 2.5 mm; interval of reconstruction, 2 mm, 120 kV, 280 mA (modulated); and noise index, 15. The scan was performed from the cerebral vertex to the pubic symphysis.

Experimental Procedures

Each experiment was performed by experts from different disciplines who collaborated closely on each case. The experimental team comprised a forensic radiographer, who was responsible for the preparation and postmortem perfusion of the body; an interventional cardiologist, who was responsible for the delivery of the aortic valve and was assisted by an engineer responsible for developing the delivery system and preparing loading procedures for the transcatheter heart valve using the 18-Fr transfemoral delivery system; and a forensic pathologist, who opened the thoracic cavity and extracted the heart.

Preparation of the body and establishment of postmortem circulation. Throughout the procedure, the bodies lay on an X-ray-compatible table. An incision of approximately 10 cm was made in the right inguinal region. Then, using surgical tools, a path to the femoral artery and vein was opened. Once each vessel has been identified and cleared from the surrounding tissue, an 18-Fr cannula (Fumedica AG, Muri, Switzerland) was inserted into both the femoral artery and vein and tightened with strings and clamps. The tubing set of the perfusion device (Virtangio; Fumedica AG) was then connected to the arterial cannula to perfuse only the arterial system. The cannula in the vein was simply connected to the reflow bag to collect the perfusion liquid draining from the body. The final positions of the cannulas are shown in Figure 1.

Because the tested aortic valves were only expandable at a physiological body temperature of about 37°C, the body had to be warmed. Therefore, the injected perfusion liquid, composed of paraffin oil, had to be heated. For this purpose it was poured into a metallic bowl that was set on a camping hot plate and placed under the perfusion device (Fig. 2). Owing to loss of heat inside the tubing system, the liquid had to be heated to 50°C to attain a temperature of about 37°C inside the body. The initial perfusion began with a volume of about 500 ml, injected at a flow rate of 500 ml/min. Further injections could be performed subsequently when needed. The flow rate was manually adapted to the anatomy of the vessels (higher flow rate to bypass stenosis) in accordance with the manipulations performed during the minimally invasive delivery of the aortic valve.

Preparation and delivery of the aortic valve. The transcatheter heart valve was rinsed to wash out the glutaraldehyde preservative and inserted inside a funnel, which eased the positioning of the connecting T bars to the catheter-loading anchor. After the connection, the bioprosthesis was pulled inside the retaining 18-Fr catheter until it was completely loaded.

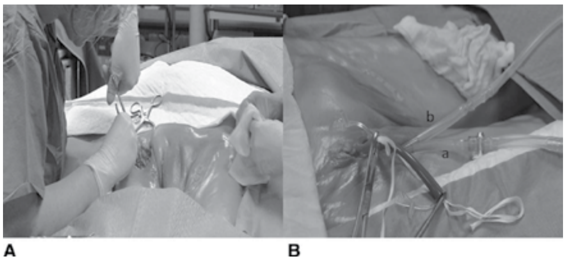


Fig. 1. Preparation of the right femoral artery and vein (**A**) and arterial (a) and venous (b) tubes fixed inside the vessels (**B**).

After its flushing ports had been flushed with 0.9% sodium chloride, the catheter was ready to be introduced.

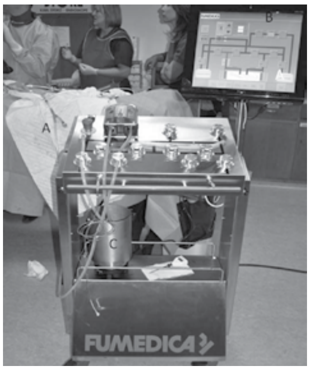


Fig. 2. Set-up for establishing postmortem perfusion. A Virtangio perfusion device was prepared for the experiment: (**A**) tubing set mounted on the perfusion device consisting of one single tube for the arterial perfusion. (**B**) Control screen with perfusion parameters. (**C**) Hot plate with metallic bowl containing paraffin oil, which was heated before it was injected into the arterial system.

For the delivery, a sheath and a dilator catheter were introduced over the wire in the femoral artery, creating the vascular access. In all cases, catheterization was performed via the artery on the contralateral side of the access site chosen for establishing postmortem circulation. The entire endovascular procedure was monitored radiologically with a mobile fluoroscopy system (Philips BV Pulsera; Philips Medical system, Eindhoven, The Netherlands). The setup is shown in Figure 3. The left ventricle was catheterized with a soft guidewire and then an exchange maneuver was performed (Fig. 4A). In this technique, used in endovascular practices, one guidewire is exchanged for another. A compatible angiographic catheter is placed over the positioned guidewire and maintained at the catheterized site while the guidewire is withdrawn. The new guidewire is subsequently introduced into the catheter lumen, and finally the catheter is withdrawn from the wire, which replaces the anterior guidewire. This maneuver allows for exchange of the existing wire without loss of the catheterized position. Once the left ventricle was accessed, a superstiff guidewire was used to maintain a secure position within the left ventricle. Using an over-the-wire device, a valvuloplasty balloon was placed at the level of the native valve and insufflated, thereby expanding the calcified valve (Fig. 4B). The balloon was then deflated and withdrawn. A 5-Fr introducer sheath and dilator catheter was placed in the right femoral artery; then a 5-Fr pigtail catheter was introduced into it and placed directly in the aortic sinus behind the noncoronary leaflet. A pigtail catheter was used for controlled injection of the contrast agent (Angiofil; Fumedica AG) until the aortic root showed a contrast "shadow," which allowed its structure to be seen without obscuring the endovascular devices. The pigtail catheter loop marked the position of the aortic annulus. The 18-Fr delivery system (New Valve Technology), with the prosthetic aortic valve loaded on to it, was placed over the superstiff guidewire; under fluoroscopic control, it was

Fig. 3. Set-up for delivery of the aortic valve. (**A**) Fluoroscopic amplifier (with plastic cover protection) to control intravascular navigation. (**B**) X-ray-compatible table with the body in dorsal position. (**C**) Clinical access for endovascular intervention in the left inguinal region. (**D**) Access for postmortem circulation in the right inguinal region.

pushed toward the native aortic valve (Fig 4C). The prosthetic valve was deployed within the aortic annulus over the native leaflets (Fig. 4D). During deployment, the temperature of the paraffin solution was kept above 37°C to allow the NITINOL stent (a nickel–titanium alloy distinguished from other materials by its shape memory and superelastic characteristics) to recover its thermomemory shape. The delivery position of the valve in relation to the annulus, based on the angiographic view, and all of the implantation characteristics were verified by fluoroscopy and recorded (Fig. 5).

Quality control of postmortem perfusion. The experimental team ensured quality control of the postmortem perfusion using a three-step scale: filling of the vascular system was considered to be good if the perfusion was done optimally in one step (no refill needed), average if the perfusion had to be executed in two or three steps (one or two refills needed), and poor if the perfusion had to be performed in several steps (multiple refills necessary).

Control of positioning. To assess the correct positioning of the implanted aortic valve, the thoracic cavity was opened according to standard autopsy guidelines (Recommendation no R (99)3, 1999) using a medial linear incision. The pericardium was opened and the heart was extracted. Special attention was paid to ensuring that the ascending aorta and the aortic arch were extracted together with the heart. The aspect and relative position of the prosthetic aortic valve to the valsalva sinus, the compression of the

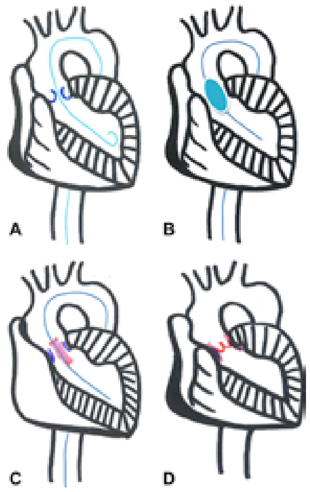


Fig. 4. (**A–D**) Schematic drawing of the procedure for a transcatheter aortic valve replacement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

native leaflets, and the calcified structure and its influence on the patency of the coronary ostia, were observed and registered (Fig. 5). In addition, the presence or absence of calcifications on the aortic valve was determined.

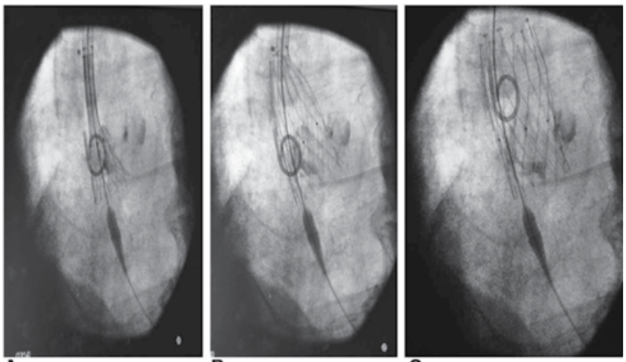
RESULTS

Postmortem CT

None of the four cases investigated by PMCT showed calcifications on the aortic valve.

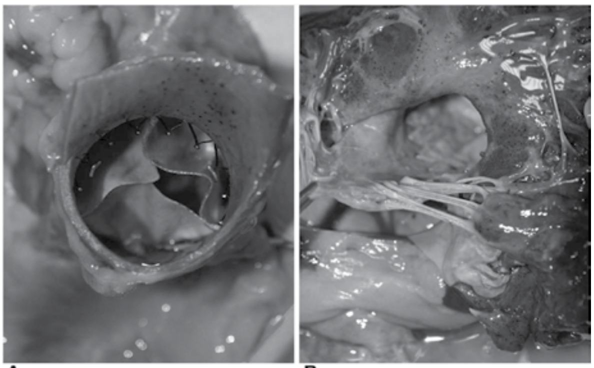
Establishment of Postmortem Circulation and Delivery of the Aortic Valve

Filling of the arterial system was good in seven of the cadavers; however, the eighth cadaver was only moderately filled. In this case, huge arteriosclerotic



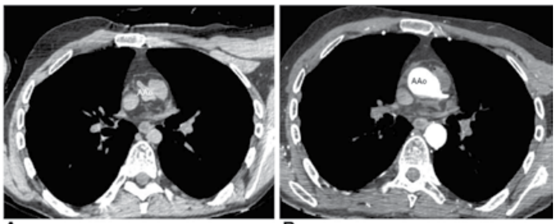
A B C

Fig. 5. Delivery of the aortic valve under X-ray control. Once the material was delivered, the self-expanding aortic valve took its original form (**A–C**).



A B

Fig. 6. Control of the position of the delivered aortic valve. (**A**) Superior view of the aortic valve after extraction of the heart. (**B**) Inferior view of the aortic valve after dissection of the left ventricle.



A B

Fig. 7. Effect of postmortem perfusion on the vascular system. (**A**) Unenhanced CT scan revealing collapsed ascending aorta (AAo). (**B**) Arterial phase of CT angiography showing the AAo expanded and filled with contrast agent (white).

plaques were observed in the abdominal aorta, which created a significant stenosis of the lumen. After refilling of the eighth cadaver, all of the cadavers were perfused, which was one of the research goals.

DISCUSSION

The present study describes a new human model for testing endovascularly delivered material. We tested this model using eight cadavers that had been embalmed by the Thiel method.

Ideal testing of endovascular procedures in human cadavers requires leak-proof, long-term circulation; arterial pulsation; and visible filling of the major vessels. In 2001, Garrett described pump-induced circulation in several isolated common arterial circuits of fresh human cadavers. This model offers realistic conditions for training clinicians in several endovascular techniques such as balloon angioplasties, expansion of stents, and stented grafts, and for investigating new devices throughout the arterial tree. Despite these merits, the absence of reperfusion of the venous system and the development of edema were significant limitations. In 2009, a similar "warm" human cadaver model was developed for testing endovascular procedures of the thoracic aorta. This model was useful but extravascular leakage was a significant finding (Arbatli et al., 2010). Recently, Aboud and Moursi (2010) reported a more life-like reperfused human training model that comprised both vascular systems, enabling training and testing procedures on the heart and major vessels. In this model, a machine provided pulsating pressure in the arteries, while constant pressure was generated in the veins. A drawback was separation of the two circulations, such that no arteriovenous circulation existed. Moreover, revascularization was limited to isolated vessel segments (Aboud and Moursi, 2010).

Experiments to establish vascular perfusion of cadavers have also been carried out to visualize the vessels of the deceased to determine the cause of death. Dynamic angiographic analyses of a whole body were initiated to explore the vascular system for this purpose. The concept of these experiments was that to perform PMCTA that would closely resemble clinical angiography, conditions would need to be similar to those in vivo. As a result, the idea arose of establishing a "postmortem circulation" that would allow for perfusion of the body (Grabherr, 2009). A first feasibility study, performed on an animal model, demonstrated that the concept was successful; diesel oil was used as the perfusate and was circulated through a roller pump (Grabherr et al., 2006). An oily perfusate was chosen because oily liquids stay within the vascular system (Zapata et al., 1989), which makes them suitable for initiating perfusion without large losses of the perfusate into the surrounding tissue, which would cause edema (Barmeyer, 1968). After successful application of the concept to an animal model, the first trials were conducted to adapt the technique to a human model. Two essential changes were made: the perfusion device was changed from a roller pump to a modified heart–lung machine, and the diesel oil was replaced by the odorless oil paraffinum perliquidum (Garrett, 2001). The images obtained revealed the vascular anatomy in detail, up to the level of arterioles. However, a major problem with the technique was a discharge of the perfusate into the stomach and the intestine; this was found to be due to a locus minoris resistentiae (Grabherr et al., 2006). This finding was not surprising, given the combination of bacterial decomposition and autolytic activities in the gastrointestinal tract, which can lead to an early increase in vascular permeability in this region. To overcome this problem, the perfusate was later changed from paraffinum perliquidum to the more viscous paraffinum liquidum (Arbatli et al., 2010). Additionally, useful materials for performing postmortem angiography have been developed recently, including a specialized and easy-to handle perfusion device and a

single-use set that contains a tubing set and oily contrast agent (Arbatli et al., 2010).

The present study describes the use of technology that was originally developed and used for forensic purposes in clinical anatomy. However, our findings suggest that it is also a useful tool for testing medical devices and materials, because it provides a model in which the conditions more closely resemble those found in living patients than the currently used animal and virtual models. To our knowledge, this is the first time this technology has been used for such a purpose.

Our experience with this approach demonstrates that, with good filling of the vessels, the placement of new materials and the training of clinicians in their delivery and use is facilitated by perfusion of the cadavers. This is because in most human cadavers, the vascular system is collapsed (Fig. 7A), which hinders the passage of endovascular catheters within blood vessels. By performing postmortem perfusion, thus filling the vessel with perfusate or a contrast agent, the vascular lumen is reopened (Fig. 7B) and endovascular navigation is enabled. A retrograde constant flow of the perfusate, supplied by the perfusion device, allows even severe stenoses to be bypassed; these would represent impassible barriers without the perfusion technique. In fact, our first experiments, performed by the same clinical team but without the presence of the postmortem team and without postmortem circulation, had to be abandoned. These failures motivated the collaboration between clinical and postmortem disciplines and also the initiation of the present study.

Although this new approach demonstrably allows for easy endoluminal navigation and delivery of the material under investigation, there are some difficulties not encountered in real clinical conditions. It was more difficult to control injections of the contrast agent than in living patients, because the contrast agent was not completely washed out of the aortic root and arch. This could be due to the retrograde flow, or to the high viscosity of the injected contrast agent Angiofil. Because the contrast agent is an oily liquid, this disadvantage could be overcome by simply decreasing its viscosity. This is done, for example, to perform microangiography (Grabherr et al., 2008a, 2008b).

Our experience also highlights the advantages of combining clinical and postmortem specialists. This collaboration allowed for direct in situ control of the implanted material without time loss, as well as fruitful interdisciplinary exchanges.

We realize that performing a native CT scan before the test procedure can help to choose those cadavers that would best match the needs of the experiment, as many medical materials are specifically developed for defined pathologies. Unfortunately, in this study, none of the radiologically screened bodies had a calcified aortic valve, which would have been very useful for our experiments.

In conclusion, the results of our experimental study reveal that the postmortem circulation model could be useful for testing endovascular material and implantation techniques. Delivery of the aortic valve system that we tested was possible with this model. Handling and tracking of the catheters was successful; all of the tested implants easily reached the implantation site, due to expansion of the vascular system and the intraluminal flow created by postmortem perfusion. The anatomical apposition of the implant with the human aortic root, its placement at the correct level within the aortic anatomy, and any interference with the coronary ostia and with the mitral valve anterior leaflet, were detectable with this new technology. This model could represent a step forward in preclinical assessments during the development of transcatheter valves and other types of endovascular devices.

REFERENCES

Aboud E, Moursi M. 2010. Live cadavers for laboratory training in vascular surgery. J Vasc Surg 51:46S–S.

Arbatli H, Cikirikcioglu M, Pektok E, Walpoth BH, Fasel J, Kalangos A, Bruszewski W, Numan F. 2010. Dynamic human cadaver model for testing the feasibility of new endovascular techniques and tools. Ann Vasc Surg 24(3):419–422.

Barmeyer J. 1968. Postmortale Koronarangiographie und Perfusion normaler und pathologisch veränderter Herzen, Messung der Durchflusskapazität interkoronarer Anastomosen. Beitr Pathol Anat 137:373–390.

Garrett HE. 2001. A human cadaveric circulation model. J Vasc Surg 33:1128–1130.

Grabherr S. 2009. Post-mortem angiography after vascular perfusion with diesel oil and a lipophilic contrast agent. In: Thali M, Dirnhofer R, Vock P, editors. The Virtopsy Approach—3D Optical and Radiological Scanning and Reconstruction in Forensic Medicine. New York: CRC Press.

Grabherr S, Djonov V, Friess A, Thali MJ, Ranner G, Vock P, Dirnhofer R. 2006. Postmortem angiography after vascular perfusion with diesel oil and a lipophilic contrast agent. AJR 187: W515–W523.

Grabherr S, Doenz F, Steger B, Dirnhofer R, Dominguez A, Sollberger B, Gygax E, Rizzo E, Chevallier C, Meuli R, Mangin P. 2011. Multi-phase post-mortem CT angiography: Development of a standardized protocol. Int J Legal Med 125:791–802.

Grabherr S, Gygax E, Sollberger B, Ross S, Oesterhelweg L, Bolliger S, Christe A, Djonov V, Thali MJ, Dirnhofer R. 2008a. Two-step post-mortem angiography with a modified heart-lung machine: Preliminary results. Am J Roentgenol 190:345–351.

Grabherr S, Hess A, Karolczak M, Thali MJ, Friess S, Kalender W, Dirnhofer R, Djonov V. 2008b. Angiofil®-mediated visualization of the vascular system by microcomputed tomography: A feasibility study. Microsc Res Tech 71:551–556.

Recommendation no R (99)3 of the committee of ministers to member states on the harmonization of medico-legal autopsy rules. Council of Europe, Committee of Ministers. Adopted by the Committee of Ministers on 2 February 1999 at the 658th meeting of the Ministers' Deputies.

Serruys PW, Piazza N, Cribier A, Webb J, Laborde J-C, de Jaegere P. (eds.) 2010. Transcatheter Aortic Valve Implantation: Tips and Tricks to Avoid Failure. New York: Informa Healthcare. 328 pp.

Thiel W. 2002. Ergänzung für die Konservierung ganzer Leichen nach W. Thiel. Ann Anat 184:267–269.

Zapata MG, Alcaraz M, Luna A. 1989. Study of postmortem blood circulation. Z Rechtsmed 103:27–32.

Rechtsmedizin 2014 · 24:107–113
DOI 10.1007/s00194-014-0947-4
Online publiziert: 20. März 2014

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Postmortale Darstellung der Koronararterien durch multiphasische Ganzkörper-CT-Angiographie

Vergleich mit Ante-mortem-Koronarangiographien

Die Diagnostik des plötzlichen Herztods durch bildgebende Techniken ist bislang unzureichend evaluiert. Als Validierungsoption für postmortale koronarangiographische Methoden steht der Sektionsbefund zur Verfügung. Sequenziell postmortal durchgeführte alternative angiographische Methoden sind denkbar. Schließlich bietet die ante mortem durchgeführte Koronarangiographie (CA) – ggf. in Verbindung mit der perkutanen transluminalen Koronarangioplastie (PTCA) – weitere Vergleichsmöglichkeiten. Neben deskriptiven sind hier auch potenziell funktionelle Aussagen zum Stenosegrad möglich.

Hintergrund

Dissektion und Beurteilung der Koronararterien gehören zu den unverzichtbaren Bestandteilen jeder Obduktion. Bei plötzlichen Todesfällen insbesondere älterer Menschen mit vorbestehender koronarer Herzkrankheit und fehlenden Korrelaten einer längeren Ischämie am Herzmuskel sind Stenosen, Obliterationen und Thrombosen in den Koronararterien häufig die entscheidenden Befunde, um den Tod auf der Grundlage der konventionellen autoptischen Diagnostik zu erklären. Bildgebende Methoden können diese Diagnostik ergänzen. Die mittlerweile mancherorts in die Routine eingeführte postmortale native Computertomographie (CT) bietet in den Koronarhauptstämmen Hinweise auf den Stenosegrad durch Kalzifikationen, kann aber qualitativ die Sektion nur selten ergänzen. Die postmortale Magnetresonanztomographie (MRT) zeigt qualitativ neue Möglichkeiten der Darstellung von perakuten und akuten Infarkten am Herzen auf und macht Koronarthrombosen sichtbar [5, 7]. Die postmortale Kontrastmitteldarstellung der Koronararterien vermag unter optimalen Bedingungen ein vollständiges Perfusionsbild der freien Lichtung im Längsverlauf wiedergeben, das in Kombination mit Schichtbildgebung multiplanar bewertet und 3-dimensional rekonstruiert werden kann [9, 10]. Die gezielte In-situ-Koronarangiographie [13, 14, 17], und die Ganzkörperangiographie (PMCTA, [6, 15]) bis hin zu einer standardisierten multiphasischen Version (multiphasische postmortale Computertomographie-Angiographie, MPMCTA, [4]) sind erfolgreich praktizierte Ansätze für die Darstellung der perfundierten Lichtungsweite der Koronarien. Neben Kontrastmitteln auf öliger Basis kommt auch ein Negativkontrast durch Gas infrage [17, 18, 21], der die wahre Gefäßlichtung im PMCT an kalzifizierten Abschnitten valider widerzuspiegeln scheint als ein auf röntgendichter Kontrastmittelflüssigkeit basierender Positivkontrast.

Insgesamt ist die Diagnostik des plötzlichen Herztods durch bildgebende Techniken bislang unzureichend evaluiert. Über die technische Evaluation angiographischer Methoden hinaus existieren Einzelberichte oder Kleinserien [13] zur diagnostischen Effizienz im Vergleich zur Obduktion, die auf hohe Übereinstimmung diagnoserelevanter Befunde hindeuten. Speziell ließen sich Koronarthrombosen als Perfusionshindernisse wiederholt darstellen [10, 12]. Detailstudien, einschließlich histopathologischer Korrelation, stehen jedoch aus.

Material und Methode

In der vorliegenden Studie wurden für eine Serie von 134 vor Obduktion durchgeführten MPMCTA an den Instituten für Rechtsmedizin in Hamburg sowie in Lausanne vorhandene klinisch dokumentierte CA recherchiert. Es fanden sich 10 Verstorbene (7 Männer, 3 Frauen, Altersspanne 54 bis 83 Jahre) mit natürlichen Todesursachen, die sich einer CA in einem prämortalen Intervall von maximal 4 Wochen unterzogen hatten. In 6 Fällen war die kardiologische Untersuchung in einem Intervall bis 96 h vor dem Tod erfolgt; in 2 weiteren Fällen war der Tod unmittelbar während der Koronarintervention eingetreten.

Die PMCTA wurde im Rahmen eines Multizenterprojekts der Technical Wor-

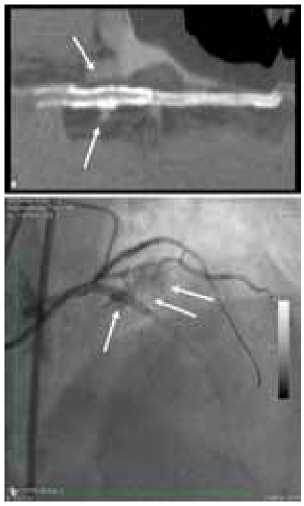

Abb. 1 ◀ **a** Multiphasische postmortale Computertomographieangiographie, arterielle Phase: Perforation der „left anterior descending (artery)" (LAD) nach Ballondilatation („Curved-mode"-Rekonstruktion), **b** Koronarangiographie: Moment der Perforation der LAD mit Kontrastmittelaustritt. *Pfeile* zeigen den Kontrastmittelaustritt

Abb. 2 ▲ **a** Multiphasische postmortale Computertomographieangiographie (MPMCTA), arterielle Phase: repetitive Füllungsdefekte in der „left anterior descending (artery)" (LAD) und dem Ramus circumflex (RCX; 3D-Rekonstruktion); **b,c** MPMCTA, dynamische Phase: „Curved-mode"-Rekonstruktion von LAD und RCX; *Pfeile* zeigen Konstrastmittelinseln, **d** Koronarangiographie: Abgangsstenosen *(Pfeile)* von LAD und RCX

king Group for Postmortem Angiograph Methods (TWGPAM, [4]) nach Standard protokoll durchgeführt [arterielle, venöse dynamische Phase über Kanülierung vo A./V. femoralis, Verwendung von 6%igen Angiofil®/94%igem Paraffinum subliqui dum; Computertomographie mit CT16 Zeiler, Standardprotokolle für Ganzkör per mit 1,0 mm sowie für Herz (in Ham burg) mit 0,8-mm-Schichtdicke]. Unter sucht wurden bei den 10 Fällen blockwei se 4 definierte Abschnitte der Koronarar terien; bei den sekundär von den Haupt stämmen abgehenden Ästen wurden le diglich proximale Anteile betrachtet:

- „left-coronary-artery"(LCA)-Hauptstamm,
- „left anterior descending (artery)" (LAD), R. diagonalis 1, R. diagonalis 2, ggf. R. intermedius,
- Ramus circumflexus (RCX), R. marginalis sinister,
- „right coronary artery" (RCA), R. marginalis dexter, R. interventricu laris posterior.

Parameter

1. *Sensitivität der MPMCTA für ante mor tem nachgewiesene intraluminale Perfu sionsstörungen*. Dazu wurde die Wieder findungsrate von Ante-mortem-Befun den in der MPMCTA untersucht. Al Perfusionsstörungen wurden vollstän dige Füllungsdefekte, also Abbrüche de Kontrastmitteldarstellung der lichten Ge fäßweite, strömungsrelevante (Stenoseg rad >70%) und nichtströmungsrelevant Stenosen unterschieden.

2. *Spezifität der MPMCTA, indem ant mortem uneingeschränkt perfundierte Ko ronarabschnitte in ihrer Post-mortem-Dar stellung kontrolliert wurden.*

Dafür wurden die aktuellen Arbeits hypothesen für die Interpretation de MPMCTA angewendet: Die uneinge schränkte Kontrastmittelfüllung eines Lu mens in mindestens einer Phase sprich gegen eine Perfusionsstörung. Überein stimmende Füllungsdefekte in mindes tens 2 Phasen sprechen für intralumina le Perfusionshindernisse (Stenosen, Post mortem- oder intravitale Thrombusbil dung, [3]).

Durch Intervention erfolgreich kor rigierte Gefäßabschnitte wurden aus de

Zusammenfassung · Abstract

Rechtsmedizin 2014 · 24:107–113 DOI 10.1007/s00194-014-0947-4

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Postmortale Darstellung der Koronararterien durch multiphasische Ganzkörper-CT-Angiographie. Vergleich mit Ante-mortem-Koronarangiographien

Zusammenfassung

Hintergrund. Dissektion und Beurteilung der Koronararterien gehören zu den unverzichtbaren Bestandteilen jeder Obduktion. Bei plötzlichen Todesfällen insbesondere älterer Menschen mit vorbestehender koronarer Herzkrankheit und fehlenden Korrelaten einer längeren Ischämie am Herzmuskel sind Stenosen, Obliterationen und Thrombosen in den Koronararterien häufig die entscheidenden Befunde, um den Tod auf der Grundlage der konventionellen autoptischen Diagnostik zu erklären. Bildgebende Methoden können diese Diagnostik ergänzen.
Ziel der Arbeit. Die Diagnostik des plötzlichen Herztodes durch bildgebende Techniken sollte evaluiert werden.
Material und Methode. Die Perfusion von 38 definierten Koronararterien-Hauptstamm-Stromgebieten wurde in der multiphasischen postmortalen Computertomographie-Angiographie (MPMCTA) bei 10 Verstorbenen mit der digitalen Filmdokumentation zeitnah vor dem Tod durchgeführter Koronarangiographien (CA), teils in Kombination mit perkutaner transluminale Angioplastie (PTCA), verglichen.
Ergebnisse. Es waren 96% der definierten Gefäßareale ohne pathologischen Befund in der CA auch in der postmortalen Angiographie unauffällig, woraus sich eine hohe Spezifität der MPMCTA für den Nachweis einer freien Gefäßperfusion ergibt. Die postmortale Gerinnung als mögliches Artefakt spielt hier eine untergeordnete Rolle. Stenosen wurden in der MPMCTA teilweise stärker gewichtet als in der CA; poststenotisch ergaben sich in 5 Stromgebieten in arterieller und dynamischer Phase der MPMCTA teils repetitive Füllungsdefekte, die auf „Fluid"-dynamische Einschränkungen des verwendeten öligen Kontrastmittels hinweisen.
Schlussfolgerung. Die Aussagekraft der Kleinserie wird durch Limitationen beim Vergleich der CA-Filmprojektionsebene mit der multiplanaren CT-Rekonstruktion eingeschränkt. Dennoch erweist sich die Ante-mortem-Bildgebung, die funktionelle Aspekte widerspiegelt, als wertvolle Option für die Interpretation der primär statischen postmortalen Koronardiagnostik durch PMCTA oder Dissektion.

Schlüsselwörter
Postmortale Bildgebung · Postmortale Angiographie · Obduktion · Postmortale Veränderungen · Kontrastmittel

Postmortem enhancement of coronary arteries by multiphase whole body CT angiography. Comparison with antemortem coronary angiography

Abstract

Background. Dissection and assessment of the coronary arteries are indispensible components of every autopsy. In cases of sudden death, particularly of elderly persons with pre-existing coronary heart disease and lack of correlates of long-term ischemia of cardiac muscle, stenosis, obliteration and thrombosis in the coronary arteries are often the decisive factors to explain the death on the basis of conventional autopsy diagnostics. Imaging techniques can be a supplemental aid for the diagnostics.
Aim. The aim of this study was to evaluate the diagnostics of sudden cardiac death using imaging techniques.
Material and methods. The perfusion quality of 38 defined coronary artery main stem flow areas as depicted by multiphase postmortem computed tomography angiography (MPMCTA) in 10 human corpses was compared with the digital film documentation of coronary angiography (CA), sometimes in combination with percutaneous transluminal angioplasty (PCTA), taken shortly before death.
Results. Of the defined vascular areas with no pathological findings in CA, 96% also had no significant findings in postmortem angiography, resulting in a high specificity for the detection of free vascular perfusion by MPMCTA. Postmortem coagulation as a possible artefact only played a minor role. Coronary stenoses were sometimes overestimated in the postmortem angiography as compared to the CA. Post-stenotic areas in five current flow areas in the arterial as well as in the dynamic phase of MPMCTA partially showed repetitive perfusion gaps suggestive of fluid dynamic limitations of the oily contrast agent used.
Conclusion. The significance of this small series is restricted by the limitations in comparing the CA film projection plane with the multiplanar CT reconstruction. Nevertheless, the inclusion of the functional aspects which are reflected by the antemortem imaging has proven to be a valuable tool in the interpretation of primary static postmortem coronary diagnostics by PMCTA or dissection.

Keywords
Postmortem imaging · Postmortem angiography · Autopsy · Postmortem changes · Contrast media

Betrachtung ausgeschlossen. Die Analyse der postmortalen Bildgebung erfolgte auf Basis pseudonymisierter Datensätze mit Osirix (64 bit). Dazu erfolgte nach Isolierung der Herzen über propagierte „regions of interest" (ROI) und „Maximum-intensity-projection"(MIP)-Modus zur Orientierung eine „3D-curved-path"-Rekonstruktion im sog. 3MPR-Modus (3D-multiplanarer Rekonstruktionsmodus; „stretched", „high resolution", Querschnitte) sowie eine 3D-Rekonstruktion in einem Standardfenster (WW216/WL196).

Die Ante-mortem-CA lagen in Form von digitalen Filmdokumentationen in mindestens 2 Standardprojektionen pro linkem/rechtem Stromgebiet vor. Stenosen wurden semiquantitativ mit Bezug auf den vorausgehenden Gefäßabschnitt abgeschätzt. Topographische Analogien zwischen dem 2D-Filmdokument einerseits und der multiplanaren bzw. 3D-Rekonstruktion andererseits erfolgten orientierend anhand anatomischer Landmarken (relative Positionen zu koronaren Richtungsänderungen und Gefäßabgängen). In einem Fall (Nr. 10) war es lediglich möglich, auf einen CA-Report mit skizzenhafter Darstellung der relevan-

Tab. 1 Fallübersicht

Fall	Beschreibung	Intervall PTA bis Tod	Lokalisation	Befunde: Ante-mortem-Koronarangiographie	Multiphasische postmortale Computertomographie-angiographie: Befund	Multiphasische postmortale Computertomographie-angiographie: Bewertung
1	M, 56 J, Tod bei PTCA durch Myokardinfarkt	Minuten	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	Abgangs-NS	Abgangs-S, RF proximal und distal	Stenosegrad falsch-positiv zu hoch, poststenotische FD-Artefakte
			RCX	Abgangs-NS; weiter distale S gestentet	FD proximal, RF vor und hinter Stent	Poststenotische FD-Artefakte
			RCA	Hauptstamm-NS	Hauptstamm-NS	Valider Stenosebefund
2	M, 76 J., Tod bei PTCA durch Perforation LCA nach Dilatation	Minuten	LCA-Hauptstamm	Perforation	*Nicht gewertet*	–
			LAD	o.B. hinter Perforation	*Nicht gewertet*	–
			RCX	o.B.	o.B.	Valide o.B.
			RCA	o.B.	o.B.	Valide o.B.
3	M, 74 J, Myokardinfarkt	17 Tage	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	NS distal D2	NS distal D2, zusätzlich Abgangs-NS D1 und D2 NS	1 valider Stenosebefund, 2 falsch-positive Abgangsstenosen
			RCX	o.B.	o.B.	Valide o.B.
			RCA	o.B.	o.B.	Valide o.B.
4	M, 60 J., dekompensierte Herzinsuffizienz	2 Tage	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	o.B.	o.B.	Valide o.B.
			RCX	o.B.	o.B. (nur 5 cm dargestellt)	Valide im proximalen Hauptstamm o.B.
			RCA	o.B.	o.B.	Valide o.B.
5	W, 71 J., Myokardinfarkt	4 Tage	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	o.B.	o.B.	Valide o.B.
			RCX	o.B.	o.B.	Valide o.B.
			RCA	o.B.	o.B.	Valide o.B.
6	M, 54 J., Aortendissektion	25 Tage	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	3 NS	Fadenförmig gefüllt nur in DP	Falsch-positive langstreckige Stenose, bei Aortendissektion
			RCX	o.B	RF proximal und distal	Falsch-positive FD, bei Aortendissektion
			RCA	*Nicht untersucht*	–	–
7	M, 69 J., Mesenterialischämie mit Darminfarkt	<24 h	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	o.B.	o.B.	Valide o.B.
			RCX	o.B.	o.B.	Valide o.B.
			RCA	o.B.	o.B.	Valide o.B.
8	W, 82 J., Myokardinfarkt	4 Tage	LCA-Hauptstamm	Stent o.B.	Stent o.B.	Valide o.B.
			LAD	S Höhe Abgang D1 gestentet, in proximalem D1 NS verblieben	FD ab proximalem D1	Falsch-positiver FD in D1
			RCX	o.B.	o.B.	Valide o.B.
			RCA	2 NS	2 NS	Valider Stenosebefund
9	M, 72 J., Myokardinfarkt	<24 h	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	o.B., RCX/LAD-Anastomosen auf Hinterwand	o.B. Anastomosen nicht deutlich dargestellt	LAD-Hauptstamm valide o.B.
			RCX	o.B.	o.B.	Valide o.B.
			RCA	Proximale S	Ab 2 cm nicht mehr perfundiert	Poststenotische FD-Artefakte

Tab. 1 Fallübersicht (Fortsetzung)						
Fall	Beschreibung	Intervall PTA bis Tod	Lokalisation	Befunde		
				Ante-mortem-Koronarangiographie	Multiphasische postmortale Computertomographieangiographie	
					Befund	Bewertung
10	W, 83 J., Myokardinfarkt	12 h	LCA-Hauptstamm	o.B.	o.B.	Valide o.B.
			LAD	Proximale NS	Proximale NS	Valider Stenosebefund
			RCX	R. marginalis sinister S – dilatiert und gestentet („90 auf 0%")	S vor Stent	Falsch-positive S?
			RCA	Abgangs-S	Abgangs-S	Valider Stenosebefund

D1/D2 R. diagonalis 1/2, *DP* dynamische Phase der multiphasischen postmortalen Computertomographie-Angiographie, *FD* Kontrastmittelfüllungsdefekte, *J* Jahre, *LAD* „left anterior descending (artery)", *LCA* „left coronary artery", *NS* nichtströmungsrelevant eingeschätzte Stenose, *o.B.* ohne Befund, *RCA* „right coronary artery", *RCX* Ramus circumflexus, *RF* repetitive Kontrastmittelfüllungsdefekte, *S* strömungsrelevant eingeschätzte Stenose.

Tab. 2 Kategorisierung der Ergebnisse der multiphasischen postmortalen Computertomographieangiographie

Koronararterie	Auswertbare Gefäße (n)	Richtig-negativ: übereinstimmend o.B. (n)	Richtig-positiv: übereinstimmender Stenosegrad/Obliteration (n)	Falsch-positiv: Stenosegrad höher als in PTA (n)	Falsch-positive Füllungsdefekte, ggf. repetitiv (n)
LCA-Hauptstamm	9	9			
LAD	9	4	2	3	2
RCX	10	5	3		1
RCA	9	7		1	2
Summe	**37**	**25**	**5**	**4**	**5**

LAD „left anterior descending (artery)", *LCA* „left-coronary-artery", *RCA* „right coronary artery", *RCX* Ramus circumflexus.

ten Befunde durch die Kardiologen zurückzugreifen, da die Originalfilme nicht auffindbar waren. Die Auswertungen erfolgten im Zweierteam mit Validierung durch einen klinischen Radiologen. Das Ergebnis der Präparation der Koronararterien im Rahmen der Obduktion wurde informatorisch einbezogen bei den Fällen, in denen gegenüber der als Validierungsmaßstab dienenden CA in der MPMCTA deklaratorisch falsch-positive Befunde vorlagen. Dieses Vorgehen wurde gewählt, da die theoretische Möglichkeit bestand, dass sich zwischen CA und Tod noch neue pathologische Gefäßveränderungen ergeben hatten.

Ergebnisse

Eine Übersicht über die Einzelbefunde aller analysierten Gefäßprovinzen zeigt ▫ **Tab. 1**. Insgesamt waren 37 Gefäßprovinzen auswertbar. In einem Fall lag keine CA der RCA vor; in einem weiteren wurde ein bei PTCA perforierter LCA-Hauptstamm mit LAD nicht gewertet (▫ **Abb. 1**). In der CA wiesen 26 Abschnitte keinen pathologischen Befund auf. In der MPMCTA wurden 25 Abschnitte (96%) als kontinuierlich perfundiert bewertet. In einem Fall war ein RCX-Hauptstamm nur abschnittweise dargestellt; hierbei war eine Dissektion der Aortenwurzel zwischen CA und Tod neu entstanden. Abgesehen von diesem Einzelfall wurden einzelne weitere falsch-positive Bewertungen in der MPMCTA beobachtet (übereinstimmend in arterieller und sog. dynamischer Phase; ▫ **Tab. 2**). So wurden teils hinsichtlich des Schweregrads von in der CA bereits diagnostizierten relativen Einschränkungen der Lichtungsweite Abweichungen festgestellt; es handelte sich um Zuspitzungen des scheinbaren Stenosegrads. Darüber hinaus fanden sich vollständige singuläre bis wiederholte Füllungsdefekte (▫ **Abb. 2**). Sie waren auf Basis der retrospektiven Auswertung zugehöriger Obduktionsprotokolle sämtlich auch nicht durch etwaige kurzfristig zwischen CA und Tod neu entstandene pathologische Gefäßwandveränderungen erklärbar.

So ergab sich in 3 Fällen im LAD ein scheinbar höherer, strömungsrelevant eingeschätzter Stenosegrad in der MPMCTA als in der CA; zweimal wurden Abgangsstenosen von LAD sowie D1-Ästen durch die Auswerter überschätzt; einmal handelte es sich wiederum um den Fall mit Aortenwurzeldissektion. Auch eine RCX-Stenose vor einem neu gesetzten Stent wurde post mortem als hochgradig bewertet, während die Kardiologen im Zuge der Stent-Implantation 12 h vor dem Tod eine Reduktion einer Stenose von „90 auf 0%" dokumentiert hatten (Fall 10; ▫ **Abb. 3**).

Schließlich waren an 5 Gefäßabschnitten postmortale singuläre oder repetitive vollständige Kontrastmittelfüllungsdefekte nachweisbar. Sie schlossen sich an in der CA nachweisbare Abgangsstenosen der Gefäße an (1-mal LAD, 1-mal RCX), fanden sich hinter einer frischen LAD-Stent-Implantation im Seitengefäß D1 oder waren im RCX in Fall 6 mit Aortendissektion aufgetreten. In Fall 9 schließlich zeigte die CA eine proximale hochgradige Stenose der RCA – mit jedoch distal weiterhin nachweisbarer, wenn auch schmalkalibriger Fortsetzung – im Gegensatz zur MPMCTA.

Als weitere Besonderheit zeigte sich in Fall 9 in der CA eine Anastomosenbildung zwischen Endästen der LAD sowie des RCX und der durch die proximale Stenose stark eingeschränkten RCA, die

Abb. 3 ▲ R. marginalis sinister aus Ramus circumflex (RCX) mit Stent-Implantation 12 h vor Tod: „90-auf-0"-Stenose, jetzt vor Stent (*roter Pfeil*) erheblich stenosiert

Abb. 4 ▲ **a** Multiphasische postmortale Computertomographieangiographie: 3D-MIP-Rekonstruktion der „left-coronary-artery" (LCA) und stenosierte „right coronary artery" (RCA, *2 Pfeile links*), **b,c** CA: langstreckige Stenose (*Pfeil* am Stenosebeginn in **b**) der RCA, aber perfundiert, Anastomosenbildung (*Pfeile*) von „left anterior descending (artery)" (LAD)/Ramus circumflexus (RCX)

in der MPMCTA allerdings nur ansatzweise mit besonders lang verfolgbaren LCA-Ästen repräsentiert war (v. a. RCX; ▫ **Abb. 4**).

Diskussion

Der Vergleich zwischen Ante-mortem-CA und postmortalem Befund ist mit zunehmendem Zeitintervall zwischen kardiologischer Untersuchung und Tod eingeschränkt geeignet. Außerdem werden in vielen Fällen die therapierelevanten Hauptbefunde durch PTCA-Interventionen am Lebenden alteriert. Insofern wird erklärlich, dass sich bei einer Zufallsauswahl von Fällen mit ante und post mortem erfolgter Darstellung der Koronararterien die Anzahl der auswertbaren, deutlich pathologischen Gefäßveränderungen in Grenzen hält. Andererseits erscheint es unabdingbar, die postmortale Bildgebung mit der Diagnostik ante mortem, wenn möglich, abzugleichen, um möglichen postmortal auftretenden Artefakten auf die Spur zu kommen. Allein postmortale Druckverhältnisse (vor, während und nach einer postmortalen Einspülung von Kontrastmittel) mit entsprechender Wanddehnung bis hin zu letztlich nichtauschließbaren postmortalen zusätzlichen Läsionen von zu Lebzeiten bereits arrodierter Gefäßwand können relevant für eine Einschränkung der Aussagekraft sein, sodass eine retrospektive Extrapolation auf die Verhältnisse am lebenden Patienten eingeschränkt gilt.

Die vorliegende Studie ist aufgrund der relativ kleinen Fallzahl und dem naturgemäß perspektivisch eingeschränkten Abbildungsvergleich zwischen CA-Filmprojektion und multiplanarer CT-Rekonstruktion in ihrer Aussagekraft begrenzt; bislang fanden sich keine Vergleichsfälle mit antemortem *CT*-basierter CA, deren hohe Sensitivität und Spezifität nachgewiesen ist [1, 2]. Die Studie zeigt aber Hinweise dafür, dass die MPMCTA sich für den Nachweis der freien Perfusion an nichtpathologisch veränderten Gefäßen uneingeschränkt eignet, wobei Gefäßdurchmesser von unter 1 mm erfasst werden. Die Sensitivität der mit wasserlöslichem Kontrastmittel durchgeführten CA in vivo für noch kleinere Kaliber wird aber – zumindest bei der derzeit verwendeten Viskosität des öligen Kontrastmittels – nicht erreicht. Bemerkenswert ist jedoch, dass die postmortale Gerinnung als mögliches angiographisches Artefakt im Koronarbereich keine größere Rolle zu spielen scheint.

Pathologische Störungen wie Koronarstenosen im Hauptstammbereich werden ebenfalls zuverlässig bestätigt, können aber in der MPMCTA-Darstellung überschätzt werden, wofür ein höheres Risiko an Gefäßabgängen im Bereich wandständiger Kalzifikationen u. a. durch Auslöschungs- bzw. Aufhärtungsartefakte [8, 19] zu bestehen scheint. Angiographie mithilfe MRT kann hier einen Vorteil bieten [16].

Schließlich bedürfen die Auswirkungen von proximal gelegenen Stenosen auf das poststenotische Füllungsverhalten des Gefäßes weiterer Klärung: „Fluid"-dynamische Interaktionen zwischen hydrophobem Kontrastmedium und verbliebenem Blut sowie Gefäßwand könnten z. B. an Gefäßbifurkationen zur bevorzugten Strömung in einen freien Gefäßabschnitt führen, sodass in den stenotischen Ast weniger Volumen pro Zeiteinheit fließt – als Folge käme es zu diskontinuierlichen Kontrastmittelinseln. Entstehende scheinbare Perfusionslücken können von echten Perfusionhindernissen ggf. durch kontinuierliche Beobachtung des Kontrastmitteleinstroms in der Fluoroskopie oder im CT-Shuttle-Mode zeitaufgelöst interpretiert und abgegrenzt werden [20]. Die derzeit gültige Arbeitshypothese der MPMCTA, dass die fehlende postmortale Perfusion von Blutgefäßen kein Beleg für ein auch ante mortem bestehendes Perfusionshindernis ist [3], kann so möglicherweise weiter differenziert werden.

Zusammenfassend ist der Vergleich mit ante mortem erstellter Bildgebung für die Interpretation der postmortalen Radiologie grundsätzlich hilfreich – beide Modalitäten können z. B. handlungsleitend für die gezielte Präparation der Koronararterien sein. Oftmals wird sich die Indikation der PMCTA im Zusammenhang mit Verdachtsfällen iatrogener Komplikationen bei der Suche nach Blutungsquellen [22] und intravaskulären klinischen Maßnahmen (z. B. Embolisierung) stellen. Bei der Suche nach Blutungsquellen kann die Methode mit einer ante mortem erstellten CA gleichwertig sein [11]. Auch die bei Sektion teils begrenzt mögliche Darstellung anatomischer Varianten von Gefäßverläufen und speziell von Anastomosen für Umgehungskreisläufe am Herzen kann gutachterlich eine wichtige Rolle spielen.

Fazit

Die Hauptstämme der Koronararterien und ihre primären Äste, die in der Antemortem-CA frei perfundierbar erscheinen, sind in der MPMCTA in der Regel ebenfalls uneingeschränkt kontrastiert. Bei einer proximalen Stenose kann es allerdings nicht nur in der arteriellen, sondern auch in der sog. dynamischen Phase der MPMCTA zu repetitiven Füllungsdefekten auch im weiteren Gefäßverlauf kommen. In der CT-basierten Angiographie können Auslöschungsartefakte durch Kalzifikationen der Gefäßwand einen Füllungsdefekt vortäuschen. Das Strömungsverhalten von verschiedenen, insbesondere öligen Kontrastmitteln in den Koronararterien ist bislang nicht ausreichend untersucht worden.

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Einhaltung der ethischen Richtlinien

Interessenkonflikt. A. Heinemann, K. Müllerleile, S. Grabherr und H. Vogel geben an, dass kein Interessenkonflikt besteht.

Alle im vorliegenden Manuskript beschriebenen Untersuchungen am Menschen wurden mit Zustimmung der zuständigen Ethikkommission, im Einklang mit nationalem Recht sowie gemäß der Deklaration von Helsinki von 1975 (in der aktuellen, überarbeiteten Fassung) durchgeführt. Von allen beteiligten Patienten liegt eine Einverständniserklärung der Angehörigen vor.

Literatur

1. Auguadro C, Manfredi M, Scalise F et al (2009) Multislice computed tomography for the evaluation of coronary bypass grafts and native coronary arteries: comparison with traditional angiography. J Cardiovasc Med (Hagerstown) 10:454–460. DOI 10.2459/JCM.0b013e3283262c85
2. Di Mario C, Sutaria N (2005) Coronary angiography in the angioplasty era: projections with a meaning. Heart 91:968–976. DOI 10.1136/hrt.2005.063107
3. Grabherr S, Grimm J, Dominguez A et al (2014) Advances in post-mortem CT-angiography. Br J Radiol DOI 10.1259/bjr.20130488
4. Grabherr S, Doenz F, Steger B et al (2011) Multi-phase post-mortem CT angiography: development of a standardized protocol. Int J Legal Med 125:791–802. DOI 10.1007/s00414-010-0526-5
5. Jackowski C, Hofmann K, Schwendener N et al (2012) Coronary thrombus and peracute myocardial infarction visualized by unenhanced postmortem MRI prior to autopsy. Forensic Sci Int 214:e16. DOI 10.1016/j.forsciint.2011.07.010
6. Jackowski C, Persson A, Thali MJ (2008) Whole body postmortem angiography with a high viscosity contrast agent solution using poly ethylene glycol as contrast agent dissolver. J Forensic Sci 53:465–468. DOI 10.1111/j.1556-4029.2008.00673.x
7. Jackowski C, Schwendener N, Grabherr S, Persson A (2013) Post-mortem cardiac 3-T magnetic resonance imaging. J Am Coll Cardiol 62:617–629. DOI 10.1016/j.jacc.2013.01.089
8. Man B de, Nuyts J, Dupont P et al (1999) Metal streak artifacts in X-ray computed tomography: a simulation study. IEEE Trans Nucl Sci 46:691–696. DOI 10.1109/23.775600
9. Michaud K, Grabherr S, Jackowski C et al (2014) Postmortem imaging of sudden cardiac death. Int J Legal Med 128:127–137. DOI 10.1007/s00414-013-0819-6
10. Michaud K, Grabherr S, Doenz F, Mangin P (2012) Evaluation of postmortem MDCT and MDCT-angiography for the investigation of sudden cardiac death related to atherosclerotic coronary artery disease. Int J Cardiovasc Imaging 28:1807–1822. DOI 10.1007/s10554-012-0012-x
11. Palmiere C, Binaghi S, Doenz F et al (2012) Detection of hemorrhage source: the diagnostic value of post-mortem CT-angiography. Forensic Sci Int 222:33–39. DOI 10.1016/j.forsciint.2012.04.031
12. Palmiere C, Lobrinus JA, Mangin P, Grabherr S (2013) Detection of coronary thrombosis after multi-phase postmortem CT-angiography. Leg Med 15:12–18. DOI 10.1016/j.legalmed.2012.08.005
13. Roberts ISD, Benamore RE, Peebles C et al (2011) Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of post-mortem coronary CT angiography. Clin Radiol 66:645–650. DOI 10.1016/j.crad.2011.01.007
14. Robinson C, Barber J, Amoroso J et al (2013) Pump injector system applied to targeted post-mortem coronary artery angiography. Int J Legal Med 127:661–666. DOI 10.1007/s00414-012-0802-7
15. Ross S, Spendlove D, Bolliger S et al (2008) Postmortem whole-body CT angiography: evaluation of two contrast media solutions. AJR Am J Roentgenol 190:1380–1389. DOI 10.2214/AJR.07.3082
16. Ruder TD, Hatch GM, Ebert LC et al (2012) Whole body postmortem magnetic resonance angiography. J Forensic Sci 57:778–782. DOI 10.1111/j.1556-4029.2011.02037.x
17. Saunders SL, Morgan B, Raj V et al (2011) Targeted post-mortem computed tomography cardiac angiography: proof of concept. Int J Legal Med 125:609–616. DOI 10.1007/s00414-011-0559-4
18. Scharf LB, Nushida H, Heinemann A, Vogel H (2010) Virtuelle Endoskopie des Herzens post mortem – Erste Ergebnisse. Fortschr Röntgenstr 182:P14. DOI 10.1055/s-0029-1247985
19. Schlungbaum W, Flesch U, Stabell U (Hrsg) (1993) Medizinische Strahlenkunde, 7. vollständig überarbeitete Aufl. de Gruyter, Berlin
20. Tashakkor AY, Nicolaou S, Leipsic J, Mancini GB John (2012) The emerging role of cardiac computed tomography for the assessment of coronary perfusion: a systematic review and meta-analysis. Can J Cardiol 28:413–422. DOI 10.1016/j.cjca.2012.02.010
21. Vogel B, Gulbins H, Reichenspurner H et al (2012) Heart Injuries in post mortem CT (PMCT). Thorac Cardiovasc Surg 60:V175. DOI 10.1055/s-0031-1297565
22. Zerlauth J-B, Doenz F, Dominguez A et al (2012) Surgical interventions with fatal outcome: utility of multi-phase postmortem CT angiography. Forensic Sci Int 225:32–41. DOI 10.1016/j.forsciint.2012.05.013

Leichenöffnung

Von der Sektion im Mittelalter zur virtuellen Autopsie der Zukunft

Nicht nur der technische Fortschritt, sondern auch wissenschaftliche Traditionen und gesellschaftliche Rahmenbedingungen haben zur veränderten Bedeutung der Leichenöffnung beigetragen. Ein medizinhistorischer Streifzug vom Mittelalter bis in die Zukunft.

Wann die Menschen angefangen haben, Tote aufzuschneiden, um zu sehen, was sich unter der Haut verbirgt, ist nicht genau bekannt. Erste Autopsien – oder Sektionen oder Obduktionen, wie die Leichenöffnung auch genannt wird – sollen bereits in der Antike, also einige Jahrhunderte vor Christi Geburt, stattgefunden haben. Zwei Gelehrte haben zu dieser Zeit die Medizin dominiert: Hippokrates von Kos und Claudius Galenos von Pergamon (Galen). Ihr Einfluss reichte bis weit ins Mittelalter. Damals begann sich an den italienischen Universitäten die wissenschaftliche Anatomie langsam zu etablieren. Die Gelehrten folgten aber weiterhin bedingungslos den Schriften Galens, der seine anatomischen Kenntnisse aus Tiersektionen (insbesondere Affen) gewonnen und – in einem aus heutiger Sicht unzulässigen Analogieschluss – auf die menschlichen Verhältnisse übertragen hatte.

Das Dogma der Humoralpathologie

Autopsien dienten im Mittelalter nicht dem Erkenntnisgewinn, sondern sollten lediglich die alten Autoritäten und ihre antike Lehrauffassung bestätigen. Im Zentrum stand noch immer das von Empedokles in Agrigent (Sizilien) eingeführte und von Galen weiterentwickelte Dogma der Humoralpathologie, das sich um die vier Körpersäfte Blut, Schleim und die gelbe und schwarze Galle drehte. Daran orientierte sich auch die damalige Diagnostik (z. B. Pulslehre) und Therapie (z. B. Aderlass, Schröpfen, Abführen). Bedeutende Fortschritte machte die Anatomie erst im 16. Jahrhundert. Erwähnt sei das Universalgenie Leonardo da Vinci. Seine 1510 angefertigten und auf Sektionen beruhenden anatomischen Zeichnungen erstaunen die Fachwelt noch heute wegen ihrer Detailtreue.

Als Begründer der modernen Anatomie gilt jedoch ein anderer: Andreas Vesalius (Vesal, 1514–1564), ein Flame deutscher Herkunft, der fünf Jahre lang als Prosektor («Vorschneider») an der Universität zu Padua arbeitete und später Leibarzt von Kaiser Karl V. wurde. Vesal veröffentlichte die erste systematische anatomische Darstellung des Menschen, die sich an den tatsächlichen Autopsiebefunden orientierte. Sein berühmtes Werk «De humani corporis fabrica» wurde erstmals 1543 in Basel gedruckt. Es vereint präzise Skelett- und Muskeldarstellungen sowie verschiedene Detailabbildungen, die alle in eine naturgetreue Landschaftsdarstellung eingebettet sind. Diese Art der Illustration – ausgeführt vom Tizian-Schüler Jan Stefan von Calacar – wurde für die damaligen anatomischen Zeichner stilbildend. Vesals Werk wurde bis ins 18. Jahrhundert immer wieder neu aufgelegt.

Mangel an toten Körpern

In der Zeit Vesals blühte das Sektionswesen in ganz Europa auf. In allen grösseren Städten entstanden «anatomische Theater», das erste 1556 in Montpellier in Frankreich. In diesen Sälen fanden die Sektionen, die sich über Tage hinziehen konnten, vor Publikum statt. Neben Fachleuten waren teilweise auch Laien zugelassen. Obwohl Papst Clemens VII. bereits 1523 die Untersuchung an Toten ausdrücklich genehmigt hatte, waren Leichen zum Sezieren weiterhin ein rares Gut. Weil meistens nur die Körper von hingerichteten Verbrechern, Prostituierten und anderen sozial Geächteten zur Verfügung standen, galt die Autopsie in der Bevölkerung als entehrend. Um zu Leichen zu kommen, schreckte manch ein Gelehrter auch vor Grabschändung nicht zurück.

Erst im 17. Jahrhundert wurden die antiken Autoritäten der Medizin endgültig überwunden. Nun begann die Epoche der empirisch-experimentellen Medizin. Eigene Beobachtung, Experimente und induktives Erkennen ersetzen das scholastische, deduktiv-logische Denken der früheren Zeit. An die Stelle der personalen Autoritäten trat die Autorität der freien Natur. Damit gewann auch die Autopsie («mit eigenen Augen sehen») weiter an Bedeutung. Krankheiten wurden nicht mehr als Ungleichgewicht der Körpersäfte verstanden, sondern die Ärzte versuchten, Krankheitssymptome mit den autoptischen Befunden in Organen und Geweben in Verbindung zu bringen. Das Mikroskop erlaubte es schliesslich, in Bereiche vorzudringen, die dem blossen Auge bisher verborgen geblieben waren.

Neben der Anatomie etablierten sich im 19. Jahrhundert auch die Pathologie und die Gerichtsmedizin als eigenständige medizinische Fachrichtungen, für die Autopsien zentral sind. Zwei herausragende Pathologen dieser Zeit waren Carl von Rokitansky in Wien – nach seinen Richtlinien wird noch heute obduziert – und Rudolf Virchow in Würzburg. Virchow ist der Begründer des zellularpathologischen Krankheitskonzepts. Demnach gehen alle Krankheitszustände des Organismus auf krankhafte Veränderungen in den Körperzellen zurück. Die Zelle ist damit die strukturelle Grundeinheit des lebenden Organismus.

Massnahme zur Qualitätssicherung

In diese Zeit fallen unzählige Entdeckungen von Krankheiten und Krankheitsursachen, die ohne Autopsie und nachfolgende mikroskopische Gewebeuntersuchung (Histologie) nicht möglich gewesen wären. Auch heute noch spielt die Obduktion eine wichtige Rolle bei der Entdeckung von neuen Krankheiten, wie Jan-Olaf Gebbers, Chefarzt am Pathologischen Institut des Kantonsspitals Luzern, betont. Erwähnt seien Aids und Sars, zu deren Verständnis die Sektion massgeblich beigetragen hat; und die Alzheimerdemenz ist nach wie vor nur beim Toten sicher zu diagnostizieren. Ab der zweiten Hälfte des 19. Jahrhunderts wurde die Leichenöffnung zunehmend auch als Instrument der medizinischen Qualitätssicherung im Spital und zur Ausbildung von jungen Ärzten eingesetzt.

Wie Gebbers erklärt, werden auch heute noch bei zehn bis zwanzig Prozent der obduzierten Leichen Befunde erhoben, die – hätte man zu Lebzeiten des Patienten davon gewusst – für die Behandlung und die Prognose wichtig gewesen wären. Und dies trotz modernen bildgebenden Verfahren und biochemischen Analysen. Dennoch sind die Autopsie-Raten an den Spitälern in den letzten Jahren weltweit eingebrochen. Vorbei die Zeiten, als noch fast jeder Verstorbene wie selbstverständlich obduziert wurde. Im Kantonsspital Luzern liege die Autopsie-Rate inzwischen bei knapp zwanzig Prozent, sagt Gebbers. Das sei bedenklich, auch im Hinblick auf die Krankheits- und Todesstatistik, die damit immer mehr auf (unsicheren) klinischen Diagnosen basiere. In dieser Hinsicht sei man wieder im Mittelalter angelangt, meint Gebbers.

Rembrandt: «Anatomie des Dr. Tulp», 1632, Öl auf Leinwand.

Ein Autopsie-Roboter

NZZ ONLINE

Pathologists Use New Tools but Are Not Defined by Them

Gregory J. Davis, MD

In keeping with the need for us, as pathologists, to engage in transformation and to reinvent ourselves as a profession,[1] Flach et al[2] at the University of Bern's Institute of Forensic Medicine (Bern, Switzerland) have eloquently shown how the use of technologies heretofore thought of as not belonging to the bailiwick of pathologists may actually be a critical adjunct study to be used with the traditional autopsy examination. In an age in which popular entertainment has given rise to unrealistic expectations of the postmortem, with fantastical notions of what information may be gleaned from it, the authors have shown information they need from the performance of such postmortem examinations.

The authors innovatively use preexisting technology in a new fashion, showing how minimally invasive computed tomography angiography may serve as a useful adjunct to the traditional autopsy of gross and microscopic inspection. Such technologic adaptation has the potential to assist in the more efficient use of autopsy resources and to aid when consent and/or resources are limited.[3] Pathologists must not be intimidated by such new uses of preexisting technology or by the adaptation to our practice of ever-evolving technologies. We must not rationalize clinging to old ways with the claim that "We've always

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Just as a family physician who uses chest radiographs is still a family physician and an obstetrician who uses ultrasound technology is still an obstetrician, we will remain pathologists upon adaptation of computed tomography or any technology, defined not by the instruments we use, but rather, by our experience, education, training, and the intelligence and wisdom with which we use them.

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Minimally Invasive Autopsy: An Alternative to Conventional Autopsy?[1]

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Purpose: To determine the diagnostic performance of minimally invasive autopsy (MIA) for detection of causes of death and to investigate the feasibility of MIA as an alternative to conventional autopsy (CA) in the clinical setting.

Materials and Methods: The institutional review board approved the MIA procedure and study, and informed consent was obtained for all deceased patients from relatives. Thirty deceased patients (19 men, 11 women; age range, 46–79 years), for whom family permission for CA on medical grounds had already been obtained, underwent additional evaluation with MIA prior to CA. MIA consisted of whole-body 16-section computed tomography (CT) and 1.5-T magnetic resonance (MR) imaging, followed by ultrasonography-guided 12-guage needle biopsy of heart, both lungs, liver, both kidneys, and spleen. Percentage agreement between MIA and CA on cause of death was evaluated. Sensitivity and corresponding 95% confidence intervals (CIs) of MIA for detection of overall (major plus minor) findings, with CA as the reference standard, were calculated. Specificity was calculated for overall findings. Sensitivity analysis was performed to explore the effect of the clustered nature of the data.

Results: In 23 patients (77%), MIA and CA were in agreement on the cause of death. Sensitivity of MIA for detection of overall findings and detection of major findings was 93% (95% CI: 90%, 96%) and 94% (95% CI: 87%, 97%), respectively. Specificity was 99% (95% CI: 98%, 99%) for detection of overall findings. MIA failed to demonstrate acute myocardial infarction as the cause of death in four patients. Sensitivity analysis indicated a negligible correlation between observations within each patient. CT was superior to MR for detection of pneumothorax and calcifications. MR was superior to CT for detection of brain abnormalities and pulmonary embolus. With biopsy only, detection of disease in 55 organs was possible, which included 27 major findings.

Conclusion: MIA is a feasible procedure with high diagnostic performance for detection of common causes of death such as pneumonia and sepsis; MIA failed to demonstrate cardiac diseases, such as acute myocardial infarction and endocarditis, as underlying cause of death.

Supplemental material:
http://radiology.rsnajnls.org/cgi/content/full/250/3/897/DC1

[1] From the Departments of Radiology (A.C.W., M.G.M.H., C.F.v.D., N.S.R., G.P.K.), Pathology (J.W.O.), and Epidemiology & Biostatistics (M.G.M.H.), Erasmus University Medical Center Rotterdam, Dr Molewaterplein 40, 3000 CA Rotterdam, the Netherlands; and Department of Health Policy and Management, Harvard School of Public Health, Boston, Mass (M.G.M.H.). Received March 4, 2008; revision requested May 16; revision received July 17; accepted August 13; final version accepted September 15. **Address correspondence to** A.C.W. (e-mail: *a.weustink@erasmusmc.nl*).

Autopsies are used for establishing the cause of death. The procedure is essential in medical education, allows for identification of new or changing diseases, and is important in the evaluation of new therapies. Furthermore, autopsies have traditionally been performed to monitor public health, produce accurate vital statistics, assess the quality of medical practice, reassure family members, and protect against false liability claims (1).

Hospital autopsy rates today are as low as 0%–10%, having decreased from a rate of 70% or higher in the 1960s (1–3). There are several reasons for this decline. Relatives withhold permission to perform an autopsy because they perceive it as mutilating to the body. One study indicated that 83% of family members that refuse autopsy felt that the patient "had suffered enough" (4). Other reasons include unawareness of the autopsy's value and religious objections. However, permission can be obtained from most members of religious groups (5,6). Sometimes clinicians simply neglect requesting permission because they believe that an autopsy is unnecessary or they feel embarrassed to ask permission for such an "unpleasant" procedure (7). The highly rated values in modern society of individuality, autonomy, and integrity of the body make it difficult for individuals to accept the perceived mutilation of a conventional autopsy (CA).

Nevertheless, in one study (8), 40% of 2479 autopsies revealed substantial information about the patient's condition beyond what was known premortem. In a study of 997 autopsies, postmortem findings provided information that would have changed management had it been available premortem in 10%–13% of cases (9). Another study reported that two-thirds of the undiagnosed conditions were considered treatable, such as infectious or malignant causes of death (10).

These outcomes emphasize the importance of the autopsy for quality control. It is generally believed that a 30%–50% autopsy rate of unselected cases is probably adequate to establish a strong quality assurance program in a general hospital (11).

In view of relatives' concerns about body mutilation with CA, the development of less-invasive postmortem examination methods may contribute to the reinstatement of the hospital autopsy. Postmortem imaging techniques are increasingly used in the forensic field. Few clinical studies have been reported on using postmortem computed tomography (CT) or magnetic resonance (MR) imaging (12–16). The aim of our study was to determine the diagnostic performance of minimally invasive autopsy (MIA) for the detection of causes of death and to investigate the feasibility of MIA as an alternative to CA in the clinical setting.

Advances in Knowledge

- There was very good agreement with respect to the cause of death (77%) between minimally invasive autopsy (MIA), combining postmortem whole-body CT and MR imaging with needle biopsy, and conventional autopsy (CA).
- MIA correctly demonstrated common causes of death, such as pneumonia and septic shock.
- The use of needle biopsy significantly increased the detection of diagnostic findings, including major findings, compared with the use of postmortem whole-body CT and MR imaging only.
- MIA was unable to demonstrate common cardiac disease, such as acute myocardial infarction, coronary artery disease, or endocarditis.

Implications for Patient Care

- MIA has potential as an alternative to CA and may help increase the autopsy rate and reinstate the autopsy as a key quality control tool in medical practice.
- Before MIA can be used as an alternative to CA, both imaging and biopsy protocols should be optimized, in particular for the detection of cardiac diseases such as acute myocardial infarction, coronary artery disease, and endocarditis.

Materials and Methods

With approval by the institutional review board, we performed a prospective cohort study. Consecutive deceased patients, for whom family permission for CA on medical grounds had already been obtained, underwent additional evaluation with MIA prior to CA whenever the treating physician asked for and received written informed consent for it and if MIA was logistically possible. Inclusion criteria were an age 18 years or older and a weight of less than 100 kg. Exclusion criteria were as follows: no informed consent from family, forensic causes of death, known or suspected "high-risk" infected cadavers (hepatitis B and C, human immunodeficiency virus, tuberculosis), and open abdominal wounds. The latter two exclusion criteria were stipulated to protect personnel collaborating on this research project. Cases referred during the weekend and on Friday were also excluded due to logistical impediments to CT and MR imaging because radiology technologists were available only from Monday to Thursday to perform imaging outside of regular working hours.

Published online
10.1148/radiol.2503080421

Radiology 2009; 250:897–904

Abbreviations:
CA = conventional autopsy
CI = confidence interval
MIA = minimally invasive autopsy

Author contributions:
Guarantors of integrity of entire study, A.C.W., C.F.v.D., J.W.O.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, A.C.W., C.F.v.D., N.S.R., J.W.O.; clinical studies, A.C.W., C.F.v.D., J.W.O.; statistical analysis, A.C.W., M.G.M.H.; and manuscript editing, all authors

Authors stated no financial relationship to disclose.

Case Recruitment

From May 2005 to January 2007, 340 deceased patients underwent CA. Written informed consent for both CA and MIA was obtained for 32 patients (Fig 1). One patient was excluded due to an MR examination failure and one patient weighed more than 100 kg. Thirty deceased patients, 19 male (age range, 46–79 years) and 11 female (age range, 47–75 years), were enrolled in the study. In four cases, the CA included autopsy of the brain. The mean age of the included cadavers at time of death was 65.7 years (range, 46–79 years). Fourteen patients were recruited from the Intensive Care Unit, eight patients from the Department of Internal Medicine, five patients from the Department of Surgery, two patients from the Department of Neurology, and one patient from the Emergency Room (Erasmus University Medical Center).

Procedure

The bodies were not embalmed prior to the MIA procedure and were stored in a standard refrigerated environment before imaging. A dedicated team transported the bodies from the pathology department to the imager directly after regular working hours. All 30 patients underwent both postmortem CT and postmortem MR imaging. Bodies were imaged in sealed body bags. The mean time between death and imaging was 9.6 hours ± 3.1 (standard deviation; range, 4–16 hours). The CT and MR imaging times were 15 minutes and 50 minutes, respectively. The mean time between imaging and CA was 15.1 hours ± 1.7 (range, 13–18 hours).

All examinations were performed with a 16-detector CT scanner (Somatom Sensation 16; Siemens, Forchheim, Germany) and a 1.5-T MR imager (Gyroscan ACS-NT; Philips, Best, the Netherlands). Imaging was performed from the calvarium to the pelvis. The CT and MR imaging parameters are listed in Tables 1 and 2. A total of 12 CT data sets were reconstructed of the head, thorax, and abdomen in coronal and sagittal planes, with a section thickness of 5.0 mm (increment, 5.0 mm) and 1.0 mm (increment, 0.6 mm) by using medium-to-smooth (B31) and very sharp (B70) convolution kernels.

Diagnostic Performance Studies

Two board-certified radiologists, unaware of CA findings but aware of the patient's clinical history, independently and systematically reviewed both CT and MR images by using a standardized checklist. The two radiologists had no previous experience in reading postmortem images. The first radiologist (C.F.v.D., with 15 years of experience) initially scored the CT study, independent of the MR study, and documented the findings; this radiologist subsequently scored the MR study. The second radiologist (N.S.R., with 5 years of experience) initially scored the MR study, independent of the CT study, and subsequently scored the CT study. In the case of disagreement, a third radiologist (with specific expertise of 10 years) was consulted in five cases, and consensus was reached during a joint session. Subsequently, one resident in radiology (A.C.W., with 3 years of radiology training), informed of the imaging findings, obtained standardized (three to five) 12-gauge needle biopsy samples from the heart and both lungs of the deceased patient, without ultrasonographic (US) guidance. US-guided biopsies were performed in both right and left liver lobes, both kidneys, and spleen. Biopsy was performed in a total of 150 organ tissues (heart, lung, liver, kidney, and spleen) in 30 patients. In three patients, biopsies of heart tissue were unsuccessful. In a patient with a bilateral pneumothorax, biopsy of lung tissue was unsuccessful. In a patient with end-stage renal disease, biopsy of kidney tissue was unsuccessful due to small kidneys. Thus, biopsy was unsuccessful in a total of five (3.3%) of 150 organ tissues.

Figure 1

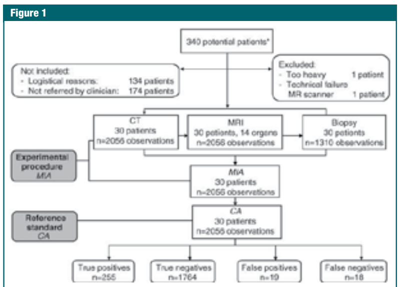

Figure 1: Flow diagram of patient inclusion and diagnostic procedures. Both MIA and CA were performed in 30 deceased patients; 14 organs were evaluated, with a range of one to eight observations per organ, for a total of 2056 observations considered. Brain autopsy was performed in only four cases. MIA was compared with CA as the reference standard.

Table 1

CT Protocols

Location	Rotation Time (sec)	Voltage (kV)	Effective Tube Current–Time Product (mAs)	Collimation (mm)	Feed per Rotation (mm)
Head	1.5	100	750	16 × 0.75	6
Thorax or abdomen	0.75	120	350	16 × 0.75	9

Additional US-guided biopsy specimens were successfully obtained of seven diseased areas in those cases in which the radiologist believed that it would aid in the diagnosis: kidney transplant, two cases; pancreas, three cases; uterus, one case; and tumor, one case. The tumor was located in the left renal cavity after left nephrectomy and represented a recurrent renal cell carcinoma. The diameter was approximately 2.0 cm.

The needle biopsy specimens were fixed in buffered formalin and processed into standard, paraffin-mounted, hemotoxylin-eosin–stained slides. If necessary, additional staining was performed—for example, to demonstrate micro-organisms (Gram stain, periodic acid-Schiff [PAS] stain after diastase digestion), to study disease of the liver (PAS stain; PAS stain after diastase digestion; stains for collagen, reticulin, and elastic fibers; stains for iron and copper) or kidney (PAS stain after diastase, Jones silver stain), or to characterize tumors (immunohistochemical stains).

One board-certified pathologist (J.W.O., with 30 years of experience), who was uninformed of the CA findings but knew of the patient's clinical history and the imaging findings, analyzed the needle biopsy specimens. When in doubt, a second pathologist (with specific expertise of at least 10 years) was consulted in eight cases, and consensus was reached during a joint session. Imaging findings were categorized as "major," which were all findings directly related to the cause of death, and "minor," which were incidental findings. The pathologists and radiologists determined the cause of death in a joint session by combining the clinical information, imaging findings, and results of needle biopsy, which together represented the MIA findings.

Residents in pathology (1–5 years of training), supervised by board-certified clinical pathologists (5–30 years of working experience) and blinded to the imaging findings, conducted a CA within 18 hours of imaging. CAs were performed according to the departmental protocol based on recent textbooks (17–19). In one case, the resident performing the CA did not comply with the standardized protocol, whereby the first opening of the pleural cavity is made under a layer of water in order to visualize escaping air to diagnose a pneumothorax. In all other cases, the CA was performed according to the standardized protocol.

Supervision of the residents entailed thorough discussion of the gross findings in the presence of the treating physicians, with the body opened and the organs dissected. The microscope slides were jointly examined by the supervisor and the resident at a double-headed microscope. Clinical board-certified pathologists (10–30 years of working experience), not informed about the MIA findings, determined the cause of death by using the combination of clinical information and the gross and microscopic autopsy findings, which together represented the CA findings.

Data Analysis

For both the MIA and the CA, the following were evaluated: brain, thyroid, heart, lungs, liver, spleen, kidneys, adrenal glands, pancreas, gastrointestinal tract, uterus, ovaries, testes, bladder, thoracic and abdominal cavities, the great arteries and veins, and lymph nodes. In 26 deceased patients for whom there was not permission for brain autopsy, imaging findings of the brain were excluded from the analysis.

The interobserver agreement for postmortem CT and MR interpretation between the two radiologists was calculated by using κ statistics (agreement: poor, <0.2; fair, 0.2–0.4; moderate, 0.4–0.6; good, 0.6–0.8; and very good, 0.8–1.0). To calculate the sensitivity and specificity of MIA for the detection of

Table 2

MR Protocols

Sequence and Technique	Orientation	Repetition Time (msec)/Echo Time (msec)	Inversion Time (msec)	No. of Signals Acquired	Section Width (mm)	Matrix	Gap (mm)
Head*							
T1-weighted spin echo	Axial	500/14		1.0	5.0	256 × 256	0.5
T2-weighted turbo spin echo	Axial, sagittal, coronal	5610/120		2.0	5.0	512 × 512	0.5
T2-weighted fluid-attenuated inversion recovery	Axial	6000/1.0	2100	2.0	4.5	256 × 256	1.0
Thorax or abdomen							
T1-weighted spin echo	Axial	450/13		2.0	5.0	256 × 256	0.5
T2-weighted turbo spin echo	Axial	2400/80		4.0	5.0	256 × 256	0.5
T2-weighted spectral fat saturation inversion recovery	Axial	2400/80		3.0	5.0	256 × 256	0.5

* MR images of the head were obtained with a head coil.

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overall findings, a number of potential observations were scored for every patient (Table E1, *http://radiology.rsnajnls.org/cgi/content/full/250/3/897/DC1*). The potential observations considered in the analysis included all findings in the study cohort. For each organ, up to eight potential observations were considered. For some organs (eg, the lungs), we considered multiple potential observations whereas for others (eg, the adrenal glands), only a single potential observation was considered.

Sensitivity and specificity and the corresponding 95% confidence intervals (CIs) (20) of MIA for the detection of overall (major plus minor) findings, with and without cardiac findings and with CA as the reference standard, were calculated. Sensitivity (and 95% CIs) was also calculated for major findings. Specificity for major findings was irrelevant because major findings were defined as findings directly related to the cause of death, and therefore no true negative outcomes existed in this data set. Causes of death determined on the basis of MIA findings were compared with the CA findings, and the proportion of agreement was calculated.

A subanalysis was performed on the additional value of needle biopsy on detection of overall findings not visible at imaging.

A sensitivity analysis was performed to explore the effect of the clustered nature of the data, as the data consisted of multiple potentially correlated observations (ie, diagnoses and organs) per patient. We reanalyzed sensitivity and specificity by using generalized estimating equations, assuming a binomial distribution of the dependent variable, a logit link function, the patient as cluster, and an equal-correlation model within each cluster (21–23). Analyses were performed with statistical software (SPSS 12.0.1, SPSS, Chicago, Ill; Stata 8.2, StataCorp, College Station, Tex).

The mean costs per patient for an MIA and a CA, respectively, were determined on the basis of an estimate of personnel, consumables, depreciation of equipment, and overhead costs (7.5%) and were expressed in U.S. dollars (24).

Results

Intracranial Findings

Three major intracranial findings, a cerebral hemorrhage in one patient and ischemic white matter changes in two patients, were observed at both MIA and CA. Of the remaining 26 patients without CA of the brain, the radiologists found white matter changes in six patients.

Diagnostic Performance

The diagnostic performance of MIA for overall and major findings, with CA as the reference standard, was very good. Only 18 of 2056 observations, including eight of 137 major findings, were missed at MIA, which yielded a sensitivity of 93% (95% CI: 90%, 96%) for overall findings and 94% (95% CI: 87%, 97%) for major findings. The major false-negative results included acute myocardial infarctions (n = 4), obstructive coronary artery disease (n = 1), gastrointestinal hemorrhage (n = 1), pneumonia (n = 1), and endocarditis (n = 1). Nineteen diagnostic findings, including three major findings, were false-positive results at MIA; together with 1764 true-negative findings, the result was a specificity of 99% (95% CI: 98%, 99%). The major false-positive results included a bilateral pneumothorax (n = 1) and pericardial effusions (n = 2).

With the exclusion of cardiac findings, sensitivity for overall and major findings was 96% (95% CI: 92%, 98%) and 98% (95% CI: 94%, 100%), respectively.

CT was superior to MR for the detection of calcifications and pneumothorax. MR was superior to CT for detection of brain abnormalities and pulmonary embolus (Fig 2). The majority of observations could be visualized with CT or MR. A total of 55 overall diagnostic findings not seen at imaging were found at microscopic evaluation of needle biopsy specimens alone in 26 (87%) of 30 patients. These included 27 major findings, directly related to the cause of death, in 14 patients (47%).

The κ statistics of the interobserver agreement for the detection of overall findings at postmortem CT and MR imaging were 0.85 and 0.84, respectively.

The sensitivity analysis exploring the effect of the clustered nature of the data demonstrated practically identical results (and 95% CIs), indicating that there was a negligible correlation between observations within each patient.

Cause of Death

There was very good agreement with respect to the cause of death (77%, 23 of 30 patients) between MIA and CA. There was agreement in the cause of death of seven patients with pneumosepsis, three with septic shock and multiple-organ failure, two with aortic dissection, two with pneumonia, two with peritonitis and sepsis, one with a colon tumor with liver metastasis, one with a heart transplant rejection and hypovolemic shock, one with hepatorenal syndrome, one with a tension pneumothorax, one with respiratory insufficiency, one with a lung bleeding, one with pneumonia and pulmonary embolus, and one patient with pneumonia. An example of a dissection of the thoracic aortic wall is shown in Figure 3. In three patients, there was partial agreement with respect to the cause of death. In the first, a severe pneumonia as the cause of heart failure was diagnosed at MIA, in contrast to endocarditis observed at CA. In the second patient, pneumonia as the cause of shock was found at MIA, in contrast to a gastrointestinal hemorrhage found at CA. In the third, acute heart failure was diagnosed as the cause of death at MIA and CA; however, only CA revealed acute myocardial infarction as the underlying cause. In three other patients, MIA failed to demonstrate acute myocardial infarction.

Costs

The mean costs (in U.S. dollars) per patient of an MIA and a CA (including brain autopsy) were \$1497 ± 148 (range, \$1190–\$1792) and \$2274 ± 104 (range, \$2056–\$2491), respectively.

Discussion

Our findings show that MIA is reliable in determining common causes of death,

such as sepsis or pneumonia. However, MIA failed to demonstrate acute myocardial infarction as the cause of death in four patients. In three other cases, MIA showed partial agreement with respect to the cause of death.

Previous clinical studies on postmortem imaging have compared only one imaging modality to CA. Bisset (13) compared postmortem MR imaging with CA in six adult patients. In the series by Patriquin et al (12), which included eight patients, MR imaging failed to demonstrate coronary artery occlusion as a major finding. Roberts et al (14) investigated the use of postmortem MR imaging in sudden unexpected death in 10 adults and reported a high correlation between MR imaging and CA findings. In one study on postmortem CT in 15 infants evaluated for suspicion of child abuse, CA was conducted in only two cases (15).

Similar to previous postmortem MR protocols (12,14,16,25,26), we performed T1-weighted, T2-weighted, and T2-weighted selective fat suppression imaging. Because of a restricted 1-hour imaging time, we used a section thickness of 4.5–5.0 mm and 1.0–4.0 signals acquired. Our CT protocol was in accordance with CT scan protocols used by others (26,27).

In our study, imaging was performed within 16 hours of death, which is a considerably shorter interval than in previous studies on postmortem imaging (12,25,26). Because of the logistics of the study, CA was delayed for 1 day in most cases. For MIA to become a feasible alternative to CA, wide access to hospital scanners for postmortem examination is a requirement. Scanning after working hours did not interfere with our regular clinical work, but doing so is not always feasible. We expect that the number of MIAs would increase if imaging could be undertaken in the morgue, which would be preferable because it would not interfere with the workflow in the radiology department for the evaluation of living patients. According to our calculations, MIA is less expensive compared with invasive CA, which is important for further implementation of this novel autopsy technique in a clinical setting.

Our study had limitations. The relatively small sample size of our study precluded the analysis of a broad spectrum of causes of death. Nevertheless, by analyzing overall diagnostic findings in multiple organs, we were able to evaluate the diagnostic performance of MIA.

The calculation of specificity of MIA for the detection of overall findings required defining which observations were relevant. Although we used an explicit and reproducible method to define a list of observations to be considered, we recognize that our method is only one possible approach. Specificity was high, which suggests that even if a shorter list of observations had been used, it would still have been high. However, there may have been selection

Figure 2

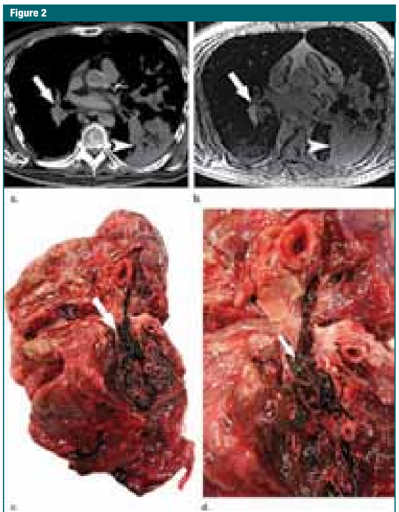


Figure 2: Pulmonary embolus as a major finding, directly related to the cause of death, in 63-year-old man with history of melanoma and cerebral vasculitis who was admitted to hospital with acute respiratory insufficiency. **(a, b)** Postmortem axial **(a)** CT and **(b)** T1-weighted MR images demonstrate a consolidation in the left lung (arrowhead). A pulmonary embolus (arrow) is clearly visualized at MR but not depicted at CT. **(c, d)** CA confirmed pulmonary embolus (arrow) as a major finding directly related to the cause of death.

bias toward more diagnostically challenging cases being referred for MIA, which may have underestimated its true sensitivity.

Another limitation is that the radiologists were unable to verify imaging findings unidentified at CA, as the body was closed directly after the CA. In future studies, verification of all imaging findings will be part of the study design. The spine was not routinely dissected at CA, rendering correlation of radiographic findings impossible. As cranial dissection was refused in most cases, postmortem CT and MR imaging of the brain could be compared with CA in only four patients. If MIA becomes more available and accepted, data will surely be forthcoming that will demonstrate the utility of MIA in this organ system.

Reference standards are rarely perfect, and in this study, a bilateral pneumothorax was missed at CA that was clearly depicted at imaging. In this particular case, the resident performing the CA did not comply with the standardized protocol. In two other cases, there was pericardial effusion detected at imaging that was too small to be noticed at CA. These three false-positive findings are in fact true-positive findings, and these cases illustrate that postmortem imaging can be superior to CA.

We unfortunately failed to record in how many cases an MIA request was denied when consent for a CA was obtained, and we have no objective information as to how often an MIA would be accepted in cases where CA is denied. Both would be useful to ascertain the acceptance of MIA.

Our results show that needle biopsy was valuable for the detection of diagnostic findings not visible at imaging. In the forensic field, postmortem CT fluoroscopy is now applied for more accurate placement of the biopsy needle in organs, including the brain (28). We did not perform CT-guided biopsies since the deceased patients were imaged in sealed body bags to offer full protection to the personnel participating in this research project and we did not want to disturb the normal routine within the clinical CT suite.

MIA failed to demonstrate ischemic heart disease, which represents a leading cause of death worldwide. New developments such as postmortem angiography can provide anatomic visualization of the human arterial system, including intracranial and coronary arteries (29). However, application of postmortem angiography is still time-consuming.

Before MIA can be implemented into clinical routine, radiologists need training in the interpretation of normal postmortem images, such as the occurrence of clotting and purification gas in small bile ducts and heart chambers, and they have to join the multidisciplinary discussion of clinicians and pathologists to fully exploit the possibilities of the minimally invasive approach to autopsies.

In conclusion, our results show that MIA is a feasible procedure with a high diagnostic performance for the detection of causes of death, with the exception of cardiac disease. Its role in central nervous system disease remains to be determined.

Figure 3

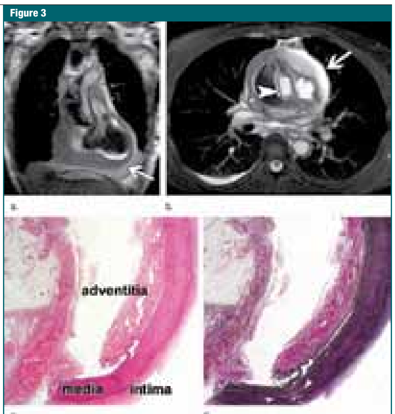
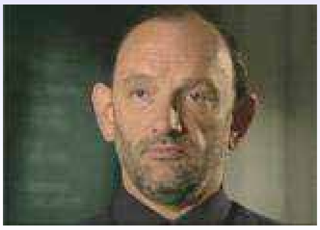


Figure 3: Dissection of thoracic aorta as cause of death in 61-year-old woman, without a medical history, who presented with acute chest pain. She died soon after entering the emergency room. **(a, b)** Postmortem **(a)** coronal T1-weighted and (**b**) axial T2-weighted MR images show dissection of the thoracic aortic wall (arrowhead), with accompanying cardiac tamponade (arrow). **(c, d)** Cross section through thoracic aorta with (**c**) hemotoxylin-eosin staining and **(d)** elastic fiber staining (both in lower power); slides show a tear between the media and the adventitia of the aorta. In **d**, the tear in the media is visible as a zigzag line (arrowheads).

References

1. Lundberg GD. Low-tech autopsies in the era of high-tech medicine: continued value for quality assurance and patient safety. JAMA 1998;280(14):1273–1274.
2. Marwick C. Pathologists request autopsy revival. JAMA 1995;273(24):1889–1891.
3. Shojania KG, Burton EC. The vanishing nonforensic autopsy. N Engl J Med 2008;358(9):873–875.
4. Hinchliffe SA, Godfrey HW, Hind CR. Attitudes of junior medical staff to requesting permission for autopsy. Postgrad Med J 1994;70(822):292–294.
5. Dorff EN. End-of-life: Jewish perspectives. Lancet 2005;366(9488):862–865.
6. Geller SA. Religious attitudes and the autopsy. Arch Pathol Lab Med 1984;108(6):494–496.
7. Sinard JH. Factors affecting autopsy rates, autopsy request rates, and autopsy findings at a large academic medical center. Exp Mol Pathol 2001;70(3):333–343.
8. Zarbo RJ, Baker PB, Howanitz PJ. The autopsy as a performance measurement tool: diagnostic discrepancies and unresolved clinical questions—a College of American Pathologists Q-Probes study of 2479 autopsies from 248 institutions. Arch Pathol Lab Med 1999;123(3):191–198.
9. Kajiwara JK, Zucoloto S, Manço AR, Muccillo G, Barbieri MA. Accuracy of clinical diagnoses in a teaching hospital: a review of 997 autopsies. J Intern Med 1993;234(2):181–187.
10. Nichols L, Aronica P, Babe C. Are autopsies obsolete? Am J Clin Pathol 1998;110(2):210–218.
11. Yesner R, Robinson MJ, Goldman L, Reichert CM, Engel L. A symposium on the autopsy. Pathol Annu 1985;20(pt 1):441–477.
12. Patriquin L, Kassarjian A, Barish M, et al. Postmortem whole-body magnetic resonance imaging as an adjunct to autopsy: preliminary clinical experience. J Magn Reson Imaging 2001;13(2):277–287.
13. Bisset R. Magnetic resonance imaging may be alternative to necropsy. BMJ 1998;317(7170):1450.
14. Roberts IS, Benbow EW, Bisset R, et al. Accuracy of magnetic resonance imaging in determining cause of sudden death in adults: comparison with conventional autopsy. Histopathology 2003;42(5):424–430.
15. Oyake Y, Aoki T, Shiotani S, et al. Postmortem computed tomography for detecting causes of sudden death in infants and children: retrospective review of cases. Radiat Med 2006;24(7):493–502.
16. Ezawa H, Yoneyama R, Kandatsu S, Yoshikawa K, Tsujii H, Harigaya K. Introduction of autopsy imaging redefines the concept of autopsy: 37 cases of clinical experience. Pathol Int 2003;53(12):865–873.
17. Finkbeiner WE, Ursell PC, Davis RL. Autopsy pathology: a manual and atlas. New York, NY: Churchill Livingstone, 2004.
18. Rutty GN. Essentials of autopsy practice: new advances, trends and developments. London, England: Springer-Verlag, 2007.
19. Sheaff MT, Hopster DJ. Post mortem technique handbook. New York, NY: Springer-Verlag, 2004.
20. Berry CC. A tutorial on confidence intervals for proportions in diagnostic radiology. AJR Am J Roentgenol 1990;154(3):477–480.
21. Zhou XH, Obuchowski NA, McClish DK. Statistical methods in diagnostic medicine. New York, NY: Wiley-Interscience, 2002.
22. Fleiss JL, Levin B, Cho Paik M. Statistical methods for rates and proportions. 3rd ed. New York, NY: Wiley, 2003.
23. Smith PJ, Hadgu A. Sensitivity and specificity for correlated observations. Stat Med 1992;11(11):1503–1509.
24. Euro to U.S. dollars conversion. Exchange Rate Web site. http://www.exchange-rate.org. Accessed March 4, 2008.
25. Ros PR, Li KC, Vo P, Baer H, Staab EV. Preautopsy magnetic resonance imaging: initial experience. Magn Reson Imaging 1990;8(3):303–308.
26. Thali MJ, Yen K, Schweitzer W, et al. Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI)—a feasibility study. J Forensic Sci 2003;48(2):386–403.
27. Paperno S, Riepert T, Krug B, et al. Value of postmortem computed tomography in comparison to autopsy [in German]. Rofo 2005;177(1):130–136.
28. Aghayev E, Thali MJ, Sonnenschein M, Jackowski C, Dirnhofer R, Vock P. Postmortem tissue sampling using computed tomography guidance. Forensic Sci Int 2007;166(2–3):199–203.
29. Grabherr S, Gygax E, Sollberger B, et al. Two-step postmortem angiography with a modified heart-lung machine: preliminary results. AJR Am J Roentgenol 2008;190(2):345–351.

Comment of chief-medical examiner Dr. D. Fowler, Baltimore/USA



highly respected practitionershighly respected practitioners
in the field of forensic medicine. In these interviews,
they talk about their work and the current state of the field.

http://www.nlm.nih.gov/visibleproofs/galleries/media/examiners/index.html

"Virtopsy is obviously just two words which have been put together and it really is a virtual autopsy. What we're doing there is we're trying to get the same amount of information from a deceased human being without actually having to make an incision on the body and therefore leaving the body completely intact.
On a day to day basis the immediate benefits of bringing Virtopsy into the office would be the ability to take certain cases that we are forced to autopsy now we would be able to scan them in six minutes, return them to the family and therefore not have to deal with those cases in the autopsy room. …
When one looks at the cost of the equipment necessary for doing a Virtopsy ….
One is that initial capital cost and the second is your operating costs. … .
In real dollar amount it's equivalent to the salary of about six or seven forensic pathologists for one year so it would certainly pay for itself in two to three years fairly easily and therefore it's not difficult to rationalize that"…

Daily Bulletin

CT Autopsy Preserves Evidence, Saves Money and Time

CT autopsy could replace conventional autopsy in determining the cause of certain accidental deaths, according to a study presented Tuesday to the news media at RSNA 2007.

"CT is a sensitive imaging tool for detecting injuries and cause of death in victims of blunt trauma," said Barry Daly M.D., a professor of radiology at the University of Maryland School of Medicine in Baltimore. "When there are major injuries, such as those resulting from a motor vehicle accident, CT may provide enough information to enable a conventional autopsy to be avoided altogether."

In Dr. Daly's study, 20 autopsies were performed using whole-body multidetector CT and interpretations by two radiologists compared with results of a conventional autopsy performed on each body. Included were 14 victims of blunt trauma and 6 victims of a penetrating wound. CT accurately identified the cause of death in all 14 blunt trauma cases and 5 of the penetrating wound cases.

"What we're essentially doing is providing the pathologist with a GPS of the body."

"If they can make the technology smaller and somewhat cheaper, I think every medical examiner's office in the country would want one. …

John Getz AFIP/USA

Science Echo

Death Takes an MRI

Television police dramas revel in showing the coroner up to her elbows in the bloody innards of a corpse. However, modern scanning technologies may soon allow forensic pathologists to crack cases without cutting into dead bodies, a team of Swiss researchers reports. Even so, some experts caution that a "virtual autopsy" can never replace the real thing.

Used in combination, computerized tomography and magnetic resonance imaging (MRI) scans can reveal the cause of death while leaving a corpse unsullied, say forensic pathologist Michael Thali of the University of Bern, Switzerland, and colleagues. In the past 3 years, they have performed 100 virtual autopsies on corpses from crime and accident scenes, followed up with traditional dissection to verify that the scans had accurately determined the cause of death, Thali reported 3 December at a meeting of the Radiological Society of North America in Chicago. A virtual autopsy might also prove more palatable to the family of the deceased, Thali says.

Media Echo

4A DAILY BULLETIN • MONDAY, DECEMBER 1, 2003

Virtual Autopsies Performed in Switzerland

Imaging technology is changing the way autopsies are conducted in Switzerland.

Physicians at the University Berne's Institute of Forensic Medicine, in collaboration with its Institute of Diagnostic Radiology, have performed 100 virtual autopsies over the past three years. Virtual autopsy, or Virtopsy®, combines CT and MR imaging.

Michael Thali, M.D., a board-certified

• Технологии • Версия для печати

15:14 07.12.2003

FIDÈS JOURNAL.COM

Médecine légale

L'autopsie virtuelle

Baptisée Virtopsy, cette méthode com[...] les techniques d'imagerie à résonance magnétique (IRM) et de tomographie à rayons-X assistée par ordinateur.

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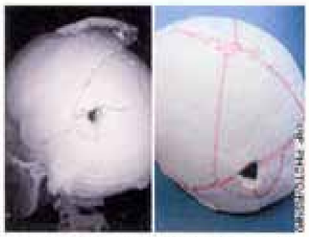
HEALTH

'Virtual autopsies' may cut scalpel role

Thursday, December 4, 2003 Posted: 10:26 AM EST (1526 GMT)

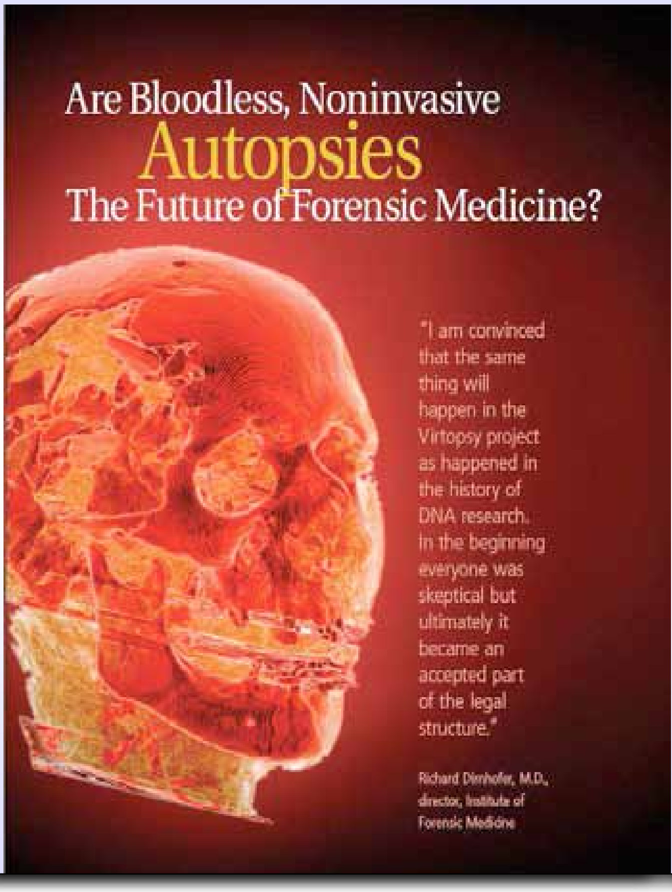
CHICAGO, Illinois (AP) -- In the not-too-distant future, autopsies might be performed using computerized scanning rather than scalpels if research led by a Swiss forensic pathologist bears fruit.

The "virtual autopsy" as envisioned and practiced by Dr. Michael Thali and colleagues at the University of Berne's Institute of Forensic Medicine is a minimally invasive procedure that relies on high technology rather than sharp implements.



The current method of showing a bullet exit wound and skull fracture, right, compared to a 3D reconstruction, left, with computer simulations of impact.

Science Echo



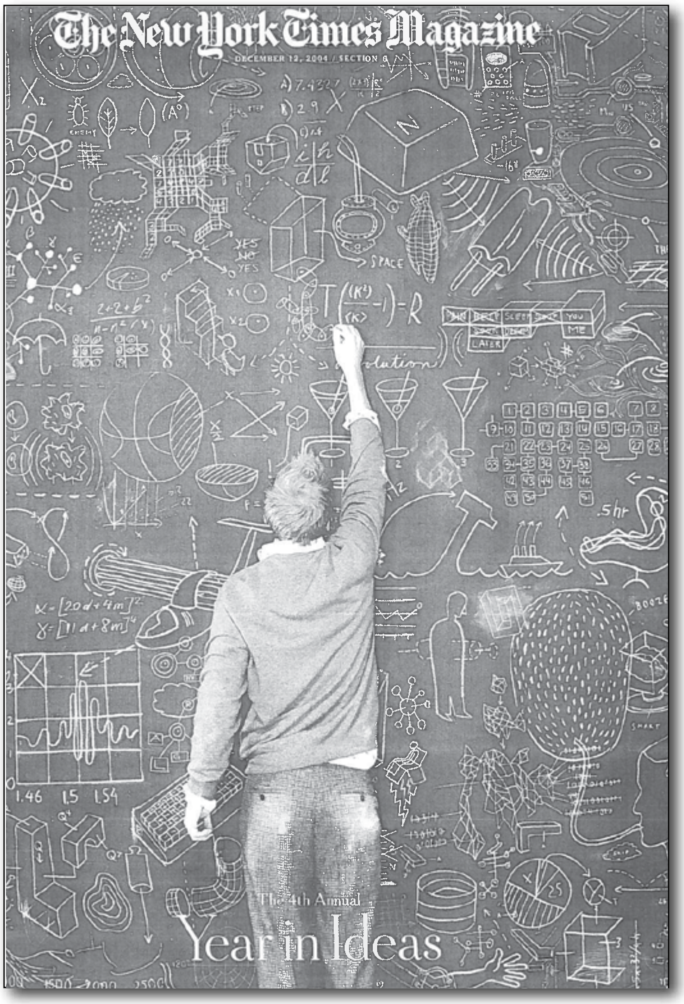
Scanner

Comparison to the evolution of the forensic DNA Technology

LEXICON

Virtopsies *n.*—**Autopsies that use noninvasive body scans and 3-D imaging**

USAGE: "**Virtopsies** combine 3-D imaging of a body's surface with a CT scan of its interior anatomy. The result is a faithful, high-resolution virtual double of the corpse. This double can be used to accurately determine what killed someone."
—*New Scientist*, Oct. 27, 2009



limpness in the movements of a key character, the diminutive fashion diva Edna Mode. Her skirt appeared to sag and crumple as she walked. The animators could have taken the trouble to iron out the glitches frame by frame. But they devised a more clever solution: the studio fitted Edna with a virtual petticoat. While her underwear is never actually seen onscreen, it nonetheless helps keep her clothing in place.

Welcome to the world of invisible animation. Hollywood's computer animators have had great success when it comes to depicting the human body in motion. Their portrayal of shirts, pants and jackets has proved to be equally lifelike and impressive. But when animators program computer systems to mimic the way interwoven fibers interact with skin — that is, when virtual clothing is put on the virtual person — the results are hard to predict and often go awry. Simulated cloth routinely gets snagged in armpits and groins or flutters and tangles spontaneously. Directors simply do not know in advance what an ordinary shirt will do once it is fitted to a moving torso.

In the face of persistent wardrobe malfunctions, animators have discovered the virtues of introducing a virtual garment that cannot be seen onscreen but nonetheless alters the computer modeling in a desirable way. For instance, when Tom Hanks's conductor's jacket in "Polar Express" kept flapping violently in the wind, it was easier to wrap him inside an invisible shroud than to smooth the jacket out by hand.

And while testing a scene of "The Incredibles" in which the once-dashing Mr. Incredible is demoted to a dead-end insurance job, animators noticed that his barrel chest kept tugging his button-down shirt out of his trousers. Rather than repeatedly halting production to tuck the shirt back in, they fell back on an old costuming trick and simply sewed his shirttails into a custom-fitted pair of virtual briefs. JASCHA HOFFMAN

Vaporized, Oxygenated Cocktail, The / Paris Hilton, things are looking up! An English businessman named Dominic Simler has created a machine that takes hard liquor and reconstitutes it as a breathable mist, which Simler claims is a low-calorie, low-carb, non-hangover-inducing way to consume alcohol.

The invention is called AWOL (Alcohol Without Liquid), and it looks, well, like a crack pipe, or maybe like an asthma inhaler (but mostly like a crack pipe). The device consists of two parts — the vaporizer, into which you pour your liquor of choice, and the oxygen generator, which pumps oxygen through a tube connected to the vaporizer, producing a mist that is then inhaled into the lungs.

AWOL was introduced in the United Kingdom in 2003, and early this year a company called Spirit Partners purchased a license to market the device in the United States. While the AWOL USA Web site celebrates the "euphoric high" from inhaling oxygenated and vaporized alcohol, various public-health and law-enforcement puritans, looking to ruin everyone's good, clean, liquor-breathing fun, have raised a few concerns.

For one, it turns out that alcohol inhaled through the AWOL machine goes into the lungs and is then dispersed into the bloodstream, which critics contend can get users drunk much more quickly and intensely than those who prefer their cocktails the old-fashioned, absorbed-through-the-small-intestine way. To ward off possible alcohol toxicity from binge breathing, the AWOL machine is calibrated so that it takes 15 minutes to inhale one shot of hard liquor, and its inventor recommends that users don't exceed two sessions in a 24-hour period.

Seems fair enough — and yet in the days leading up to the machine's American debut at the Manhattan night club Trust, Attorney General Eliot Spitzer, responding to the concerns of local politicians, referred the question of AWOL's legality to the New York State Liquor Authority. So Spirit Partners unveiled its magical machine usin Gatorade instead of alcohol, fearing it might otherwise violate a Nev York state law dating back to 1934 that prohibits the dispensing of al cohol from a different container than the one it was delivered in.

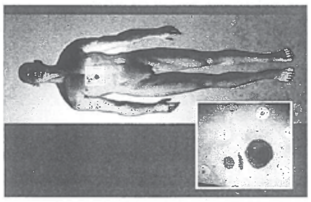
Apparently vaporized liquor is no lower in calories and carbo hydrates than liquid alcohol, and there's no proof that it doesn' produce hangovers. But what neither Eliot Spitzer nor "science" no any of the buzzkills at the New York State Liquor Authority can den is that, in the words of one anonymous enthusiast quoted by Spiri Partners, "this is the greatest thing since the still." JOEL LOVEL

Virtopsy / A traditional autopsy begins with a deep Y-shaped inci sion in the chest. Next, the skin is peeled back to expose the ri cage, which must be sawed open with a bone cutter so that variou organs can be removed and examined. Such near-eviscerations ar rarely very tidy.

A team of forensic scientists from Switzerland is trying to mak this procedure a little more aesthetically pleasing. Since 2000, Mi chael Thali and colleagues at the University of Bern's Institutes c Forensic Medicine and Diagnostic Radiology have been developin a bloodless and noninvasive form of digital autopsy. Their Virtops Project uses nearly $2 million worth of C.T. (Computed Tomogra phy), M.R.I. (magnetic resonance imaging) and 3-D surface-scan ning technology. With Virtopsy, the pathologist has only to press button and scan the body — and wait a few minutes. What result is a digitally embalmed body stored on a workstation, a "corpse that can be viewed from any angle or depth. "It's like a virtu flight through the data set," Thali explains. "You start at the hea and go through the thorax, abdomen and pelvis, right down to th legs." A click of the mouse will remove a layer of skin, muscle o connective tissue from the skeleton as if it were a piece of clothing

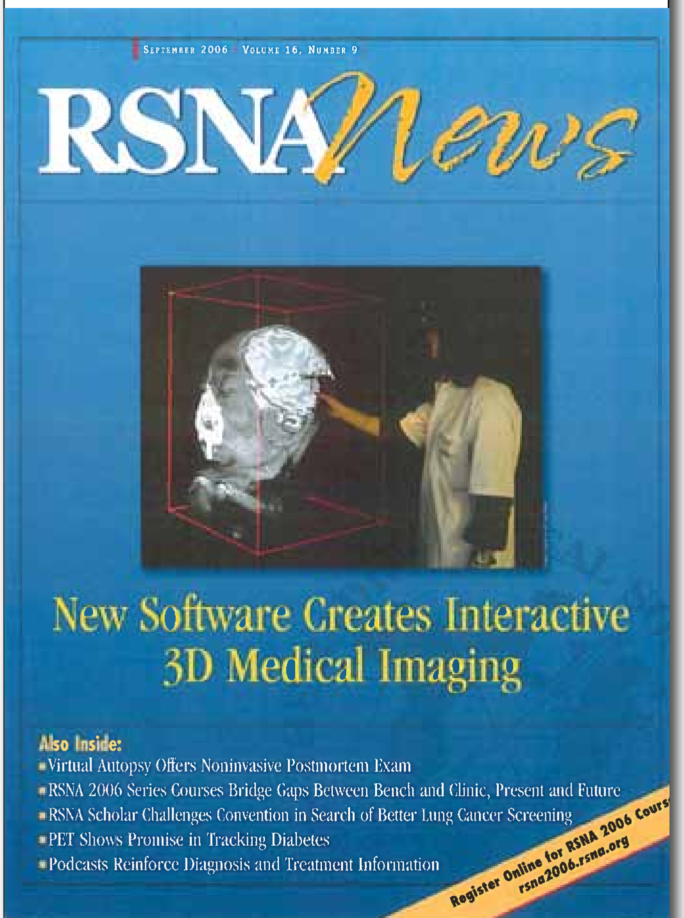
Thali and his colleagues have already performed more than 10 virtopsies, with each virtual analysis confirmed by an actual autop sy afterward. While Thali is cautious to note that virtopsy is "still little baby," with years of further research required, the procedur has caught the interest of the United States Department of De fense. Last month, Dover Air Force Base in Delaware installed Virtopsy system to facilitate the analysis and processing of de ceased soldiers. RYAN BIGG

Virtual Sketch Artist, The / For years, crime witnesses have bee asked to come down to the police station and describe crim suspects to sketch artists. Recently, though, psychologists hav found that when witnesses try to describe a face, they often distor



A shotgun wound localized on a scanned body and in a detailed scanned view.
VIRTOPSY

IMAGES FROM VIRTOPSY RESEARCH GROUP UNIVERSITY OF BER



FEATURE HOT TOPIC

Virtual Autopsy Offers Noninvasive Postmortem Exam

POWERFUL new technologies are yielding postmortem images that allow medical examiners to comprehensively understand cause of death while avoiding some of the drawbacks of traditional scalpel autopsy.

In the past, determining cause of death meant careful examination of the body by dissection—a time-consuming, expensive procedure some cultures find objectionable.

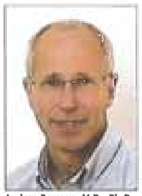
On the other hand, virtual autopsy, as it is generally known, uses CT and MR imaging to capture detailed images of cadavers. Radiologists can then create 3D visualizations that enable pathologists, coroners and medical examiners to investigate the condition of the body for clues to the cause and manner of death.

Swiss pioneers of the technology have trademarked the name Virtopsy® to describe their unique forensic reconstruction strategy that combines different imaging methods—CT, MR imaging, image guided biopsy and postmortem angiography, among others—with special database and application software. These researchers have drawn the interest of the National Institutes of Health, which most recently included their work in the "Visible Proofs: Forensic Views of the Body" exhibition showing at the National Library of Medicine through February 16, 2008.

Postmortem imaging is not new, but the advent of 3D imaging technology has made it much more applicable to forensic medicine. Examiners now have options traditional scalpel autopsy could not offer.

"Diagnostic imaging is still underused in forensics, mainly due to unawareness of its potential and the lack of teaching and experience," said Richard Dirnhofer, M.D., founder and manager of the Virtopsy Project at the University of Bern in Switzerland.

Richard Dirnhofer, M.D.
University of Bern



Anders Persson, M.D., Ph.D.
Linkoping University

Dr. Dirnhofer is the lead author of "VIRTOPSY: Minimally Invasive, Imaging-guided Virtual Autopsy," appearing in the September-October issue of *RadioGraphics*.

Dr. Dirnhofer sees parallels between Virtopsy and the DNA research that began 20 years ago and recently culminated in sequencing the human genome. DNA sequencing was fraught with the same anxiety and hand-wringing over expense, said Dr. Dirnhofer, that he sees some colleagues experiencing about Virtopsy.

> *Once you do a traditional autopsy, it's difficult to look at the wounds—the skull fragments fall apart. On the CT scan, you can visualize the injury pattern or where the injury occurred.*
>
> **Commander Craig Mallak, M.D.**

"We are now in the research phase, which is a difficult time for Virtopsy," he said. The feasibility has been shown, he said, but now the technology must hold up to repeated testing. "As with DNA, it will be a step-by-step process," he said.

Permanence and Ease are Advantages

Given that forensic evidence doesn't last forever, virtual autopsy's most obvious advantage is that it creates a 3D image—a permanent record that can be studied, archived or sent on to others.

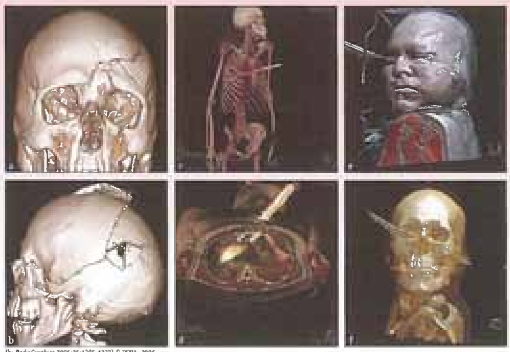
"It is easy to have objective documentation after a virtual autopsy," said Anders Persson, M.D., Ph.D., director of the Center for Medical Image Science and Visualization (CMIV) at Sweden's Linkoping University. "You can reproduce it, give it to a third party or look at it again in 10 years."

Ease of documentation also makes virtual autopsy particularly well-suited for use as courtroom evidence, taking the place of graphic or disturbing photographs.

"You can also see different versions from different angles," said Graham Segal, O.A.M., an Australian barrister-at-law and chair of the first virtual autopsy conference, held late last year in Sydney. "For example, if you're looking at the passage of a bullet, you can manipulate the image to enable a variety of understandings."

Cultural Impact is Significant

Another key benefit of virtual autopsy is that it allows investigation without



(a) 3D reconstruction of a pistol shot-bursting fracture of the skull and (b) characteristic exit wound of the skull with an outwardly split margin.
Images courtesy of Richard Dirnhofer, M.D.

(c) and (d) In these cases, findings from whole body CT scans pointed to suicide with cuts on the arms and the neck. The angle between the knife and the body also suggested suicide. Findings in both cases were confirmed at autopsy.

(e) and (f) A CT scan helped determine that the knife to the head did not kill this murder victim. The cause of death was 10 stab wounds in the heart. The CT scan saved investigators about 10 hours compared with the traditional autopsy scheme.
Images courtesy of Anders Persson, M.D., Ph.D.

destroying the body, a procedure many people of different faiths and cultures find invasive or offensive. People of Jewish and Muslim faiths believe most autopsies violate religious laws, said Segal, while others find the idea of autopsy on relatives distasteful or unnecessary. "You have the decorum of a funeral, interrupted by a slight detour to the chopping block—that's the way some people see it," he said.

Segal also points to a variety of injuries and trauma—including facial fractures, drowning, strangulation and gunshot wounds—that are easier to identify through imaging rather than scalpel autopsy.

Added Dr. Persson, "Our software can amplify the very small fragments that you can't see with the naked eye."

Military Examiners Find Use

Virtual autopsy also is helping military examiners find the exact causes of death for soldiers killed in the line of duty. At the forefront is the U.S. Armed Forces Institute of Pathology (AFIP), which performs CT-assisted autopsy.

Commander Craig Mallak, M.D., an AFIP medical examiner, said he believes that CT helps examiners more quickly localize certain abnormalities than was possible using past procedures.

"In the old 2D days, we had no idea what plane a bullet was laying in without taking a series of x-rays," he said. "Now, we run the body through a CT scanner and we know exactly where to look for the projectile." CT-assisted autopsy also picks up a lot of subtle injuries not seen in traditional autopsy, he said. In certain areas that might not traditionally have been examined, the CT scan now guides the hands of the pathologist.

Dr. Mallak said he believes virtual autopsy can sometimes offer better information than traditional autopsy, particularly in trauma cases. For example, imaging enhances the recovery of projectiles, which is often helpful with trauma such as severe head injuries, he said.

"Once you do a traditional autopsy, it's difficult to look at the wounds—the skull fragments fall apart," Dr. Mallack said. "But on the CT scan, you can visualize the injury pattern or where the injury occurred."

Despite its capabilities, few predict that imaging will completely replace the scalpel in the future. Most agree virtual autopsy works best as a supplement to traditional autopsy. Dr. Mallack noted that certain injuries are not well-visualized on CT, adding, "You can't get toxicology samples or recover bullets from a scan."

Virtual Autopsy also a Triage Tool

Some also foresee virtual autopsy as a screening tool for mass casualties from natural disasters or terrorism.

"In a scenario where you have mass casualties and the medical examiner can't possibly autopsy every person, it can help you figure out which body needs an autopsy," said Colonel Angela Levy, M.D., who works with Dr. Mallack at AFIP.

Dr. Mallak said Hurricane Katrina provides a potent example. "You had bodies that had decomposed and you

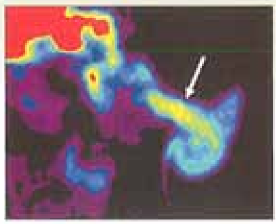
Continued on page 9

processes in the body where they are taking place. "The beauty is that the study would be very easy to perform and pain free for the patient," said Dr. Votaw, who is teaching the PET and PET/CT segment of an RSNA 2006 minicourse on innovations and advances in radionuclide imaging technology.

While cautioning that the study was performed only in genetically altered rats, leaving a considerable amount of work to be done before the techniques are demonstrated effective in humans, Dr. Votaw called the findings important and promising. Researchers may have found a way to measure changes in the body that would lead to diabetes before the patient experiences any symptoms, he said.

"With this information, it may be possible to treat the disease sooner and more effectively," he said. "And the proposed PET assay would be far preferable to a biopsy of the pancreas to obtain the same information."

Dr. Votaw said the results are positive not only from a diagnostic perspective, but also from a basic science point of view. "This work could lead to a better understanding of how cells produce insulin," he said. "A better understanding of the underlying biology in normal tissue is always promising for developing therapies for diseased tissue."



Coronal reconstruction of an abdominal dynamic PET scan with [11C] DTBZ in a male baboon. The pancreas is indicated in these summed frames by the arrow.
Photo courtesy of Paul E. Harris, Ph.D.

Human Studies Set to Begin

Dr. Harris said his team is about to begin human studies on healthy volunteers and people who have had Type 1 diabetes for a long time. "That means they're completely insulin dependent, which suggests they have no beta cells left in their pancreas," he said. "We hope that by studying the differences between them and healthy volunteers, we'll be able to see differences in uptake of the radiopharmaceutical."

If the technique continues to prove successful, PET imaging could eventually find use in diagnosis and treatment of increasingly prevalent Type 2 diabetes, said Dr. Harris.

"While Type 2 diabetes is not identical to Type 1 diabetes, the end result in Type 2 is often still beta cell loss and eventual insulin dependence," he said. "One of the goals in treating Type 2 diabetes is to halt that beta cell loss process. Until now, there has been no reliable endpoint to determine whether a drug is stopping beta cell loss or not."

If PET imaging to measure beta cells works well in humans, Dr. Harris added, the pharmaceutical industry may also be interested in using PET as an endpoint marker for studying drug efficacy.

The full text of the study "Longitudinal Noninvasive PET-Based β Cell Mass Estimates in a Spontaneous Diabetes Rat Model" is available at *www.jci.org/cgi/content/full/116/6/1506.*

Virtual Autopsy Offers Noninvasive Postmortem Exam

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couldn't tell whether they had suffered trauma or simply drowned," he said. "Using a CT scan would be a good triage tool."

Many argue imaging, despite employing cutting-edge technology, is less expensive than traditional autopsies. Scanning the dead "is cheaper per case because it's so much quicker," said Segal. "It's less labor intensive, so you need less staff at the morgue."

Reading postmortem scans does present new challenges for radiologists. "It's not the same as looking at the living," said Dr. Persson. "One important issue is postmortem gas. After a day or so, you find gas in the skeleton, in the soft tissue; it's popping up everywhere. It's hard to see if it's gas from bowels or from the wound."

Radiologists can learn only by looking at many cases, said Dr. Persson. "There are no books; it's a completely new area," he said.

With that newness, however, comes continual discovery.

"You never know what you're going to find," said Dr. Mallak. "We've been surprised by what we've seen in the images, but that's good. This isn't fantasy anymore; it's reality."

To read the abstract for the article, "VIRTOPSY: Minimally Invasive, Imaging-guided Virtual Autopsy," go to *radiographics.rsnajnls.org/cgi/content/abstract/26/5/1305.*

For more information about the "Visible Proofs: Forensic Views of the Body" exhibition at the National Library of Medicine, go to *www.nlm.nih.gov/visibleproofs/exhibition/.*

Advances in forensic imaging bring new opportunities for radiology