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SHORT ORIGINAL ARTICLE / *Technical*

The usefulness of post-mortem CT angiography in injuries caused by falling from considerable heights: Three fatal cases

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Abstract
Objective: Post-mortem computed tomography is a diagnostic tool forming part of the arsenal available to forensic pathologists today. In addition to its usefulness in detecting bone lesions, which has long been recognized, this technique has nowadays been enhanced by the development of CT angiography. The role of multiphase post-mortem computed tomography angiography (multiphase PMCTA) is primordial, improving detection of solid organ lesions and permitting vascular lesions to be visualized directly.
Material and methods: Our paper presents a series of three deaths by falling from a considerable height recorded since the beginning of 2012. We report the usefulness of PMCTA and the various mechanisms involved in the trauma.
Results: Most of the lesions were diagnosed by both PMCTA and autopsy, including the rare lesions, but the peripheral bone lesions and the hemopneumatocele were diagnosed only by PMCTA, while dislocation of vertebrae and the testicular fractures were detected solely by autopsy.
Conclusion: PMCTA is a new, minimally-invasive technique which, combined with autopsy, provides better visualization and detection of certain lesions, particularly in the case of death by falling from a great height.

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Post-mortem computed tomography is an important diagnostic tool in modern forensic medicine. This technique was introduced about 10 years ago, and various research studies have proved its usefulness, particularly for post-traumatic bone lesions [1,2]. The recent introduction of post-mortem computed tomography angiography seems promising, despite its use being restricted to a few sites. Indeed, this new addition to post-mortem imaging has a role to play in the detection of vascular and solid organ lesions [3,4].

At the start of 2012, the departments of forensic medicine and radiology of our establishment introduced post-mortem computed tomography angiography (PMCTA). In this paper, we report three cases of death by falling out of a window or from a considerable height.

The aim of this paper is to throw light on the usefulness of PMCTA, while emphasizing the different lesions encountered in this type of trauma and the mechanisms causing them.

Material and methods

Summaries of the cases

Between May and July 2012, three cases of death by falling from a height were studied. These examinations were performed by order of the court. The first case (F1) was an 81-year-old woman known to have suicidal tendencies. Her body was found under the fourth floor window of her home for the elderly. There was no evidence of break-in when the body was removed. The original position of the body was unknown because of attempts at lifesaving. The second case (M) was a 45-year-old man known for psychiatric hospitalization and repeated suicide attempts. He was found under the window of his fourth floor apartment. The apartment was closed, and a suicide note was found. The body was moved by the emergency ambulance team. The third case (F2) was a 60-year-old woman, also known for a history of suicide attempts. The body was found under her balcony on the second floor. The heights of the falls were estimated as 13, 12 and 5 m respectively.

Preparation of the bodies

Before the PMCTA, each body was prepared by inserting surgical femoral arterial and venous cannulae (Maquet GmbH & co. KG, Rastatt, Germany). The examination consisted of a non-injected stage, performed with a 16-detector CT scanner (Sensation 16, Siemens, Erlangen, Germany). This stage was also used to obtain the biological samples for toxicology tests (systematically bile and urine, other body fluids if present). The controlled perfusion machine used (Virtango, Fumedica AG, Muri, Switzerland), was developed by Swiss teams at the University Forensic Medicine Center of Lausanne and Geneva [3].

The second step was the injection of a special contrast agent (Angiofil®) to obtain contrast enhanced CT acquisitions in three different phases: arterial, venous and dynamic (arterial injection with concomitant venous aspiration).

Radiological and autopsy interpretation

The data collected by PMCTA were interpreted by two radiologists (FZM and FD) and took place before autopsy. The CT examinations were also read again after each autopsy. Finally, the results of the two techniques were compared.

Results

Table 1 summarizes the most important lesions in each case studied described by the two techniques (PMCTA and autopsy). The lesions were classified by organ but also by frequency: typical lesions frequently found (Table 1, Typical lesions), and lesions described in the literature but rarely visualized in practice (Table 1, Atypical lesions). Most of the lesions were diagnosed by both techniques (autopsy and PMCTA), such as the traumatic encephalic, thoracic and abdominal lesions. Certain diagnoses were only established by autopsy, e.g. T7-T8 disc dislocation (F1), the humeral fractures (F1 and M), and testicular fractures/contusions (M). The diagnoses made only with PMCTA were hemopneumatocele (F1), fractures of the head of the fibula and a metacarpal bone (M). In addition to the lesions typically described in trauma by falling, rare lesions were found: a double aortic rupture (F1: Fig. 6) and postostial detachment of the right coronary artery (M: Fig. 3). These lesions were seen with both techniques.

Discussion

Post-mortem CT angiography is a new technique, still under study, used in only a few centers in the world. Ours is the only establishment to practice this technique in France [3]. The method is based on a minimally-invasive technique, requiring vascular denudation of the femoral vessels using a 15 cm incision in the fold of the groin. However, other micro-invasive techniques have already been described in an attempt to perform CT examination with a contrast agent [5].

In order to confirm the presence of a lesion, particularly a vascular lesion, the teams using this new technique have agreed that a pathological image must be found on at least two of the three injected phases (arterial, venous or dynamic). All the vascular lesions confirmed by PMCTA complied with this rule [6].

The lesions typically found following a fall from a considerable height are well documented [1]. They usually result from deceleration mechanisms. All the typical lesions were diagnosed by the two techniques, PMCTA and autopsy. Nevertheless, there were some fine distinctions.

All the vascular lesions were clearly confirmed by PMCTA, which increased the sensitivity of their detection during autopsy, and helped with the dissection technique. The fractures of the posterior curvatures of the ribs, lesions typically related to rapid deceleration, were underestimated by the autopsy. This was mainly due to the difficulty of gaining access to this anatomical region during the autopsy. This can also be said of the hemopneumatocele, because dissection

Table 1 Summary of the different lesions observed by post-mortem computed tomography (PMCTA) and then by autopsy.

Lesions	Region	Organ	Type of lesion	PMCTA	Autopsy
Typical lesions	Cephalic extremity	Brain	Cerebellar subdural hematoma (F1)	+	+
			Subarachnoid hemorrhage (M)	+	+
			Perfusion asymmetry at the expense of the right hemisphere due to an internal carotid lesion (F2: Fig. 1)	+	+
			Fracture of bones of the skull (F1: Fig. 2, F2)	+, +	+, +
	Thoracic organs	Heart	Laceration of the inferior vena cava extending to the right atrium (M: Fig. 3)	+	+
		Mediastinum	Pericardial laceration communicating with the right pleural space (M)	+	+
			Hemopericardium (M)	+	+
		Lungs	Multiple lung lacerations, combined with parenchymal contusions (F1, M, F2: Fig. 4)	+, +, +	+, +, +
			Intra-alveolar hemorrhage (F1, M, F2: Fig. 4)	+, +, +	+, +, +
			Right hemopneumatocele (F1)	+	−
		Pleura	Bilateral hemopneumothorax (F1, M, F2)	+, +, +	+, +, +
		Thoracic wall	Bilateral multiple costal fractures (F1, M, F2: Fig. 4)	±, ±, ±	±, ±, ±
	Abdomen		Hemoperitoneum (F1: Fig. 5, F2)	+, +	+, +
			Diaphragmatic laceration/hiatus hernia (F1)	+	+
			Liver fractures (F1: Fig. 5, F2)	+, +	+, +
			Lesions of the left renal artery and the right renal vein (F1)	+	+
			Right testicular fracture, left testicular contusion (M)	−	+
	Limbs	Upper limbs	Left (M) and right (F1) fractures of the humerus	−	+
			Fracture of the left 2nd metacarpal (M)	+	−
		Lower limbs	Tibial and bilateral fibular fracture (M)	+	+
			Fracture of the head of the right fibula (M)	+	−
	Pelvic girdle		Multiple fractures of the bones of the girdle (F1, M)	+, +	+, +
	Vertebral column		Lumbar vertebral fractures (M)	+	+
			T7-T8 disc dislocation (F1)	−	+
Atypical lesions	Thoracic organs	Heart	Detachment of the right coronary arteries (M: Fig. 3)	+	+
		Mediastinum	Double aortic laceration (F1: Fig. 6)	+	+

F1: first female case; F2: second female case; M: male case; +: lesion diagnosed by the examination; −: lesion not diagnosed; ±: disagreement between the two examinations to varying degrees.

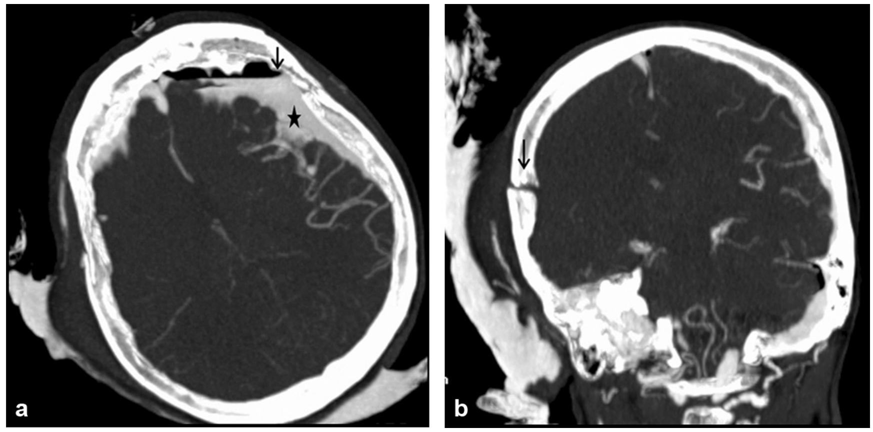

Figure 1. Case F2. Maximum Intensity Projection (MIP) reconstructions, PMCTA: dynamic phase. Lack of perfusion of the right cerebral hemisphere, following rupture of the right internal carotid artery: a: axial reconstruction. Extravasation of contrast agent into the pericerebral space (black star), with pneumocephalus (black arrow); b: coronal reconstruction showing a fracture of the right parietal bone (black arrow).

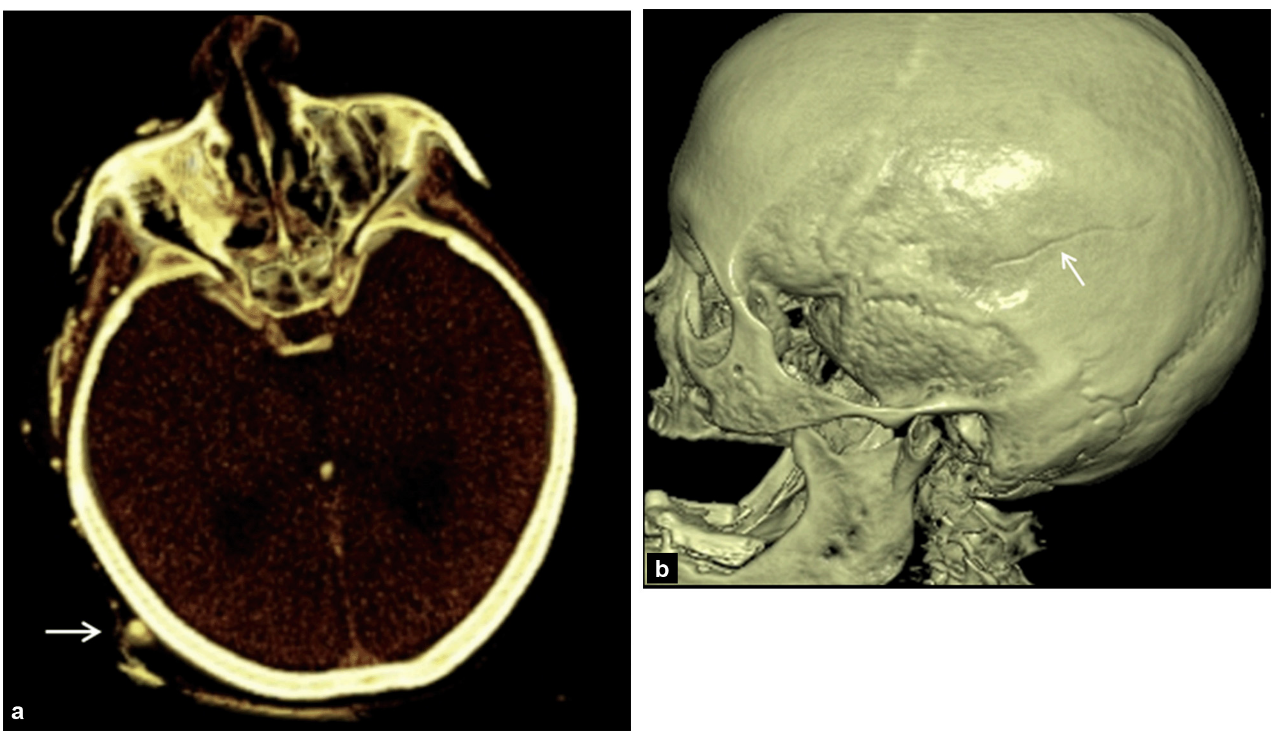

Figure 2. Case F1. Volume Rendering Technique (VRT) reconstructions: a: superior axial view. PMCTA: venous phase, showing extravasation of contrast agent into the pericranial soft tissues indicating a hematoma (white arrow); b: sagittal reconstruction showing a fracture of the right parietal bone (white arrow).

of the lungs causes the air/fluid collection to collapse and makes it difficult to diagnose this.

On the other hand, some lesions were only visible in the autopsy. Soft tissues, such as the testes, show poor contrast in CT, making diagnosis of any lesions difficult. Dislocation of the thoracic disc was visualized in the CT scan, but was considered to be degenerative.

The humeral fractures could not be visualized by CT because the irradiated field did not encompass the entire upper appendicular skeleton.

The rare lesions (double aortic rupture and detachment of the right coronary) were clearly identified by the two diagnostic approaches. The epidemiology and the mechanisms incriminated in aortic ruptures have been widely studied [7,8]. Depending on the series, aortic ruptures resulting from falling from a height make up between 5 and 15% of traumatic aortic lesions, well below the number from road traffic accidents. The special feature of our case was the combination of an isthmic lesion and a lesion of the descending aorta. Multifocal aortic lesions including the descending aorta are the rarest [9].

Coronary detachments are rare and little documented. This is probably due to the difficulty of demonstrating them by standard techniques. The existence of this type of lesion

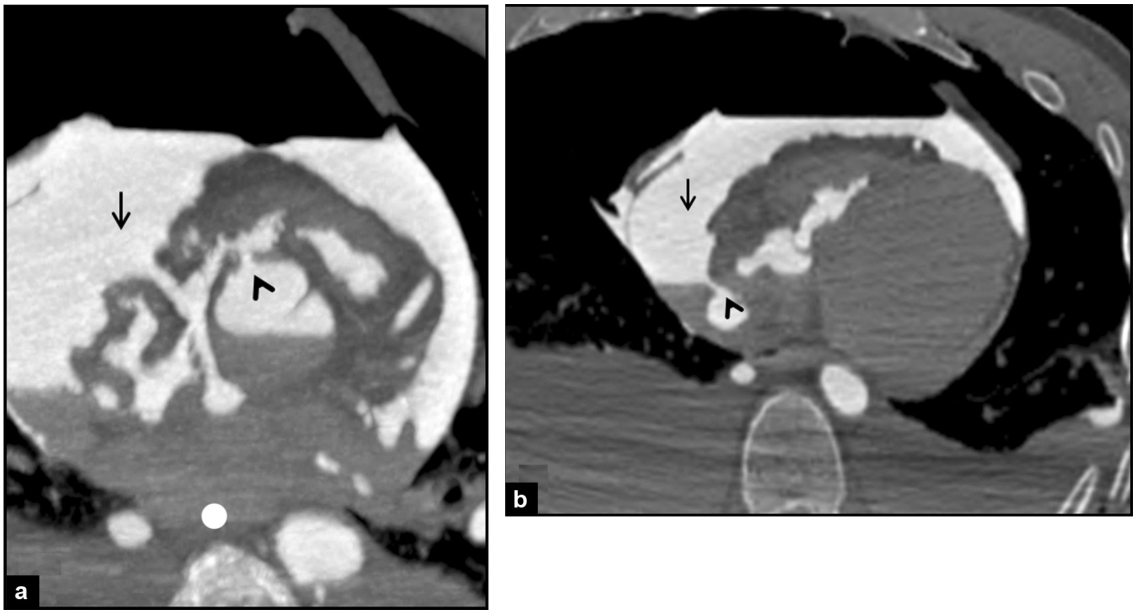

Figure 3. Case M. MIP axial reconstruction, PMCTA: dynamic phase: a: detachment of the right coronary artery (white star). Hemopericardium (black arrow); b: visualization of a gap at the atrial insertion of the inferior vena cava (arrowhead), responsible for extravasation of the contrast agent into the pericardium (black arrow).

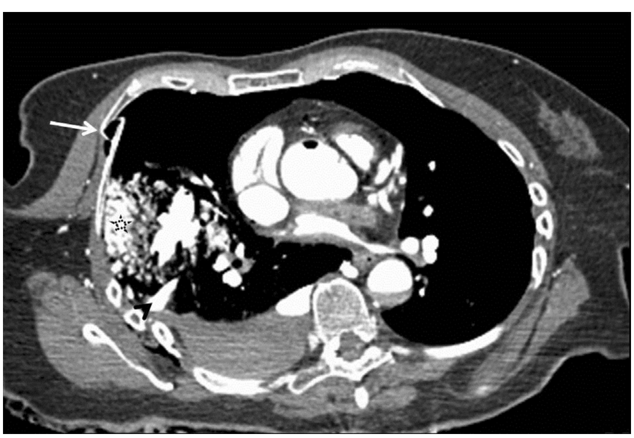

Figure 4. Case F2. Axial thoracic slice. Multiphase PMCTA: dynamic phase. Multiple parenchymal lung lesions (dotted star), intraparenchymal contrast agent extravasation (black arrowhead), and presence of a displaced costal fracture (white arrow).

emphasizes the force of the distraction and torsion resulting from rapid deceleration in falls from a height. This type of coronary lesion has not previously been linked to falls from heights, but only to road accidents and the projection of objects [8,9].

PMCTA has certain limitations. Apart from those related to human personnel (the need for trained and dedicated staff), technical limits (the necessity for surgical cannulation, the availability of premises), limitations of equipment (the assignment of equipment, including a special injection machine) and financial limits (there is currently no validated tariff for this procedure), PMCTA also requires a trained radiologist who is aware of the diagnostic traps [1,6]. For example, post-mortem thrombi in the pulmonary arteries are artifacts, which for the moment do not allow pulmonary embolism to be diagnosed. Analysis of the parenchyma

Figure 5. Case F1. Oblique coronal reconstruction with MIP. PMCTA: dynamic phase, showing multiple liver lacerations (white arrows), combined with intraperitoneal extravasation of contrast agent (black star).

of solid organs is also still poorer than in an autopsy, although clearly better than in non-contrast enhanced CT [6].

Studies published to date confirm that PMCTA complements autopsy. This is all the truer where vascular lesions are concerned. However, this new technique makes it possible to include the chronology of lesions at the time of death. For example, in the case of M the lesions occurred as follows: rupture of the inferior vena cava with detachment of

Figure 6. Case F1. Oblique sagittal view with MIP. PMCTA: arterial phase: a: rupture of the aortic isthmus (white arrow); b: rupture of the descending thoracic aorta (white arrows).

the right coronary artery, hemopericardium, communication between the pericardium and the pleura via a penetrating costal fracture, hemopneumothorax. Despite extravasation of the contrast agent in the injected sequences, the absence of hemoretroperitoneum on the non-contrast enhanced sequence indicated that the multiple fractures of the bony pelvis were not directly responsible for the death.

Conclusion

The PMCTA study of three cases of death due to falling from a considerable height has brought to light various lesions associated with fatal rapid deceleration. Compared with non-contrast enhanced CT, PMCTA is more sensitive, particularly for detecting vascular lesions, and thus makes their presence known so that they can be carefully looked for during the autopsy. With CT angiography, one can move on from diagnosis based on indirect signs to diagnosis from direct visualization of vascular lesions. The rare lesions reported in this paper have not been hitherto connected with falls from a considerable height. In addition, this new technique includes the ability to establish the chronology of lesions at the time of death.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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