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# Drowning—post-mortem imaging findings by computed tomography

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**Abstract** The aim of this study was to identify the classic autopsy signs of drowning in post-mortem multislice computed tomography (MSCT). Therefore, the post-mortem pre-autopsy MSCT- findings of ten drowning cases were correlated with autopsy and statistically compared with the post-mortem MSCT of 20 non-drowning cases. Fluid in the airways was present in all drowning cases. Central aspiration in either the trachea or the main bronchi was usually observed. Consecutive bronchospasm caused emphysema aquosum. Sixty percent of drowning cases showed a mosaic pattern of the lung parenchyma due to regions of hypo- and hyperperfused lung areas of aspiration. The resorption of fresh water in the lung resulted in hypodensity of the blood representing haemodilution and possible heart failure. Swallowed water distended the stomach and duodenum; and inflow of water filled the paranasal sinuses (100%). All the typical findings of drowning, except Paltau's spots, were detected using post-mortem MSCT, and a good correlation of MSCT and autopsy was found. The advantage of MSCT was the direct detection of bronchospasm, haemodilution and water in the paranasal sinus, which is rather complicated or impossible at the classical autopsy.

**Keywords** Virtopsy · Drowning · Post-mortem · Multislice computed tomography

## Introduction

A generally used definition of drowning is given by Roll [1]: "Death by drowning is the result of a hampering of respiration by obstruction of mouth and nose by a fluid medium (usually water)". Generally, bodies retrieved from water may have: (1) died of natural disease before falling into the water, (2) died of natural disease while already in the water, (3) died from injury before being thrown into the water, (4) died of injury while in the water, (5) died of effects of immersion other than drowning, (6) died of drowning (true drowning). According to the World Health Organisation, the annual worldwide incidence of death by drowning is about 400,000 [2]. Death from drowning is more common in young children [3]. In adults, suicide is a frequent cause of drowning, which is often associated with past psychiatric history [4]. Drowning has especially been related to young adults who are under the influence of alcohol and other drugs whilst being near water [5, 6].

The pathophysiological aspects of drowning are complex.

Ten percent of drownings happen without aspiration of fluid in the lung [7, 8]; this is the so-called "dry drowning" due to a laryngospasm because of hypoxia and stimulus of water in the upper respiratory ways (larynx) [9, 10]. The remaining 90% of drownings are so-called "wet drowning": the volume and composition of aspirated fluid determine the physiological basis of hypoxemia [11–13]. Aspiration of fresh water dilutes the pulmonary surfactant and makes alveoli unstable [14], which leads to the collapse and atelectasis of some of the alveoli. Intrapulmonary shunt occurs with considerable pulmonary venous admixture [15]. The appearance of hypotonic fresh water in the alveoli is not usually a problem, because it is rapidly absorbed into the pulmonary and systemic circulation with dilution of the blood and hypervolemia [16]. The passive postmortal inflow of water is low [17–19]. On the other hand, aspiration of sea water leads to perfused and fluid-filled alveoli. The hypertonic sea water pulls additional fluid from the plasma, leading to pulmonary edema and hypovolemia and adding to the ventilation-perfusion abnormality [20, 21].

Intrabronchial water can cause substantial bronchospasm, which results in pulmonary emphysema, also known as emphysema aquosum [22]. The fluid aspiration followed by bronchospasm is more multifocally scattered throughout the lung than diffuse, which results in a mosaic pattern of dry, hypoperfused and wet, hyperperfused lung areas [23].

Pulmonary arterial hypertension and hypervolemia lead also to heart failure, accentuated on the right side.

During the act of conscious drowning a lot of water is swallowed [24], which leads to a distention of the stomach and duodenum. In addition an inflow of water into the paranasal sinuses may frequently occur [25].

For "near drowning patients", findings are already known; sand aspiration occurs [26] and pulmonary changes can be found in computed tomography (CT): predominant centrally located ground-glass opacities with or without associated reticular opacities and centrilobular nodules [27].

The intention of this paper is to present the CT findings of drowning cases and their correlation with autopsy findings.

## Materials and methods

During the period from 2000 to 2005 ten cases of true drowning were examined at the Institute of Forensic Medicine in Berne within the Virtopsy project [28]; two were female, eight male; the median age at death was 52 years, ranging from 13 to 81. MSCT and autopsy were performed at a median of 43 h and 58 h after death, respectively. According to the Virtopsy protocol, the deceased received post-mortem CT and magnetic resonance imaging (MRI), followed by the classical forensic autopsy. The control group consisted of 20 non-drowning cases, where the atrium mortis was the brain. This group consisted of six females and 14 males; the median age at death was 43, ranging from 19 to 73. MSCT and autopsy were performed at a median of 35 h and 49 h after death, respectively.

Multislice CT (MSCT) was performed on a GE Lightspeed QX/I unit (General Electric, Milwaukee,Wis., USA). Axial slices were accuired with a collimation of 4 mm× 1.25 mm; 5-mm and 1.25-mm sections, as well as sagittal and coronal reformations, were calculated. The MSCT scan took between 10 and 15 min. Two board-certified radiologists, blinded to the autopsy findings, retrospectively evaluated the CT scans in common (consensus viewing).

Autopsy was performed by board-certified forensic pathologists, which were blinded to the results of the CT studies. Classical autopsy procedure was used.

Potential forensic key findings of drowning at autopsy were looked for at MSCT of the ten drowning and 20 non-drowning cases.

The distribution, amount and content of aspiration in the airways were assessed. Since the detection of aspiration in the airways is rather easy in MSCT, its density could be measured in Hounsfield Units (HU) to characterise the content. Fluid in the airways was called "watery fluid" when the density was below 30 HU and "dense fluid" when its density was equal or higher than 30 HU. Watery fluid was further subdivided into foamy water, when bubbles of very low densities of 1 to –1,000 HU were present. The amount of aspiration was classified into three groups. It was low when it filled up to one-third of the tracheal/bronchial volume, high when it filled more than two-thirds, and was medium in-between the two.

Any multifocal ill-defined air space densities in dependent lung areas with normal calibres of the vessels were considered as signs of aspiration into the lung.

For the assessment of emphysema aquosum, the stance of the dome of the right diaphragm on the basis of the anterior ribs was determined. The minimal distance between the left and right lung was also measured (width of the retrosternal mediastinum).

Additionally, the bronchial diameters were compared with the diameters of the accompanying pulmonary artery, based on the hypothesis that aspiration leads, on one hand, to bronchospasm and, on the other hand, to dilatation of the pulmonary artery (resorption of the water). A segmental broncho-vascular bundle of the middle lobe or the lingula was examined and the bronchial-arterial coefficient (i.e. the diameter of the bronchus divided by the diameter of accompanying pulmonary artery) was calculated. The middle lobe or lingula was chosen for measuring, because the non-dependent lung areas showed less pulmonary edema and/or aspiration that troubled the exact analysis.

To evaluate laryngospasm, the posterior distance between the vocal cords was measured.

To assess heart failure, the cardio-thoracic ratio (CTR = maximum transverse cardiac diameter/transverse thoracic diameter) was measured on MSCT images and the cross sectional area of the inferior vena cava (IVC) was measured at the level below the right atrium and above the liver. The individual size of the heart chambers was acquired semi-quantitatively using a scale from 0 to 3 (0 indicating normal volume).

As signs of pulmonary edema, dependent lung areas with diffuse or multifocal air space consolidation and with interstitial opacities surrounding enlarged pulmonary vessels were looked for, as well as accompanying pleural effusion.

Since it is known that people with anemia have a lower density of blood [29], because of the low level of haemoglobin, which is a major contributor to the density of blood, haemodilution of blood in each case was assessed by measurement of the blood density in the right and left atrium. The analysis of blood density in the ventricles was not done, because the dilution effect of the blood would be too high in that non-dependent topographical location, and furthermore, a lot of postmortal gas-formation/-embolism occurs in the ventricles.

The approximate volume of the stomach was calculated using the product of stomach length, height and depth and the multiplication factor $\pi/6$, the density of the content was measured in HU. Attention to the duodenal distention and content was also given.

The amount and distribution of fluid in the paranasal sinuses was evaluated at MSCT.

The findings of the drowning and control groups were statistically compared by the Wilcoxon signed rank test. A $P \leq 0.05$ is significant and labelled with the number 1, $P < 0.01$ is considered more highly significant and marked with the number 2, and $P < 0.001$ as the most highly significant and the number 3 was assigned. 0 stands for not significant: $P > 0.05$ (Table 1).

## Results

### Aspiration

Every case (10/10) of drowning showed some content in the airways both at MSCT and at autopsy. Most of the fluid

**Table 1** Wilcoxon signed rank test: signs of drowning in MSCT are listed below in order of significance

| Signs of drowning in order of significance (Wilcoxon-test) in drowning vs non-drowning cases | Significance[b] | Mean drowning ($n$=10) | SD± | Mean non-drowning ($n$=20) | SD± |
|---|---|---|---|---|---|
| Aspiration into main bronchi[a] | 3 | 1.90 | 0.57 | 0.37 | 0.60 |
| Water in sphenoidal sinus[a] | 3 | 2.00 | 0.94 | 0.37 | 0.50 |
| Emphysema (rib level of diaphragm dome) | 3 | 5.00 | 0.67 | 4.00 | 0.53 |
| Tracheal aspiration[a] | 3 | 1.20 | 1.03 | 0.11 | 0.32 |
| Water in maxillary sinus[a] | 3 | 1.40 | 0.52 | 0.58 | 0.51 |
| Bronchospasm (bronchial-arterial coefficient) | 3 | 0.84 | 0.12 | 1.04 | 0.14 |
| Right ventricle size (semi-quantitative from 0 to 3) | 2 | 0.40 | 0.52 | 0.00 | 0.00 |
| Water in frontal sinus[a] | 2 | 1.10 | 0.99 | 0.21 | 0.42 |
| Density of airways contents (HU) | 2 | 21.90 | 10.91 | 40.45 | 16.24 |
| Haemodilution (HU of blood) | 2 | 50.00 | 16.17 | 64.05 | 9.74 |
| Density of stomach content (HU) | 2 | 20.30 | 13.74 | 38.95 | 17.99 |
| Duodenal size (semi-quantitative from 0 to 3) | 1 | 1.20 | 0.63 | 0.63 | 0.50 |
| Aspiration into peripheral bronchi[a] | 0 | 1.30 | 0.67 | 0.79 | 0.63 |
| Laryngeal spasm (glottic distance in cm) | 0 | 0.60 | 0.16 | 0.48 | 0.14 |
| Stomach volume (ml) | 0 | 470.00 | 323.35 | 275.50 | 222.51 |
| Heart size (semi-quantitative from 0 to 3) | 0 | 0.30 | 0.48 | 0.05 | 0.23 |
| Pharyngeal aspiration[a] | 0 | 0.80 | 0.42 | 0.47 | 0.51 |
| Aspiration into the lung[a] | 0 | 0.70 | 0.67 | 0.37 | 0.50 |
| Pulmonary edema[a] | 0 | 0.70 | 0.82 | 0.33 | 0.49 |
| Size of left atrium (semi-quantitative from 0 to 3) | 0 | 0.10 | 0.32 | 0.00 | 0.00 |
| Size of inferior caval vein ($cm^2$) | 0 | 4.72 | 2.31 | 5.53 | 1.34 |
| Water in ethmoidal sinus[a] | 0 | 0.80 | 0.42 | 0.58 | 0.51 |
| Water in mastoid cells[a] | 0 | 0.40 | 0.52 | 0.26 | 0.45 |
| Density of pleural effusion (HU) | 0 | 21.00 | 20.08 | 30.00 | 10.00 |
| Size of left ventricle (semi-quantitative from 0 to 3) | 0 | 0.10 | 0.32 | 0.05 | 0.23 |
| Distance between lungs (anterior mediastinum in cm) | 0 | 1.47 | 2.48 | 1.54 | 1.67 |
| Size of right atrium (semi-quantitative from 0 to 3) | 0 | 0.70 | 0.67 | 0.68 | 0.48 |
| CTR | 0 | 0.47 | 0.09 | 0.48 | 0.05 |

[a] Amount, semi-quantitative from 0 to 3

[b] 3: $P<0.001$; 2: $P<0.01$; 1: $P\leq 0.05$; 0: $P>0.05$

was found in the main bronchi (Fig. 1), where on average two-thirds of the volume was filled, in the small bronchi about half of the luminal volume was obliterated. A mean of 40% of the tracheal volume was filled by liquid at MSCT and 33% was detected at autopsy. Eighty percent of the cases showed also a small amount of watery content in the pharynx at MSCT (50% at autopsy detected).

The liquid contents of the airways consisted of a dense fluid in 30% and a watery fluid in 70%. Among the cases with dense fluid, there was one case with sandy water (40 HU), one case with gastric juice (37 HU) and one case with blood (30 HU). In the group with watery fluid, five cases showed foamy fluid of an average of 12 HU, and in two cases with sanguineous water, the density was 20 HU. The control group showed fluid in the airways or the lung in 60%, but only a small volume was present: 10–20% of the volume of the bronchi, mainly in the small bronchi, and 10% showed minimal tracheal aspiration.

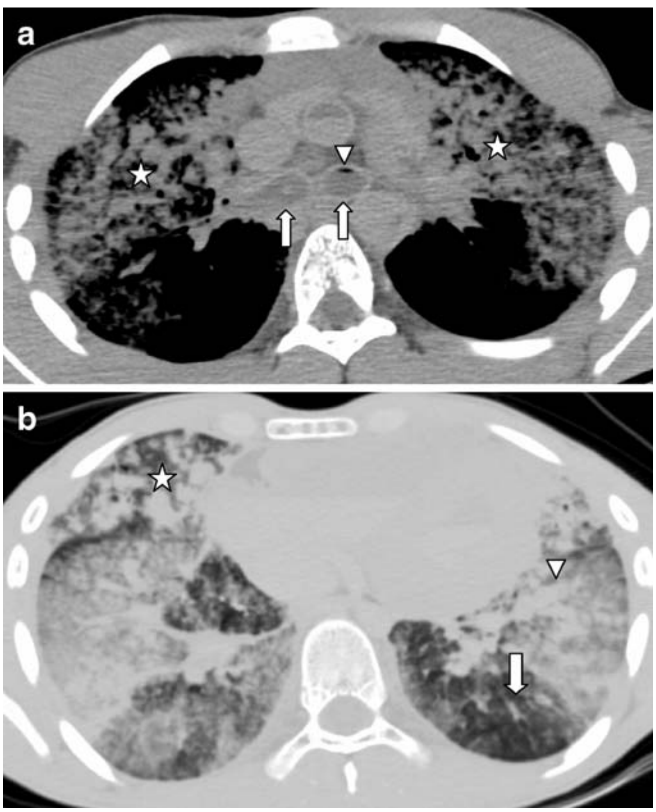


**Fig. 1** **a**, **b** Central and peripheral fresh water aspiration in MSCT. **a** Note the fluid in the main bronchi (*white arrows*) with an air/fluid level (*arrowhead*) on the left side. Air space consolitation in the upper lobes represents aspiration in the lungs (*asterisks*). **b** The lung-window at a lower level presents coarse nodular lung densities in the middle lobe, compatible with aspiration (*asterisk*). In the lower lobes there is a patchy mosaic pattern of hypoperfused (hypodense) and hyperperfused (hyperdense) lung areas. Note the diameter of the vessels: in the hypodense areas the vessels appear smaller (*arrow*) than in the edematous hyperdense areas (*arrowhead*)

Aspiration into the trachea and the main bronchi was significantly more severe in the drowning group than in the control group (Table 1). Radiologically, 60% of the cases had aspirated fluid into the lung (Fig. 1), whereas at autopsy aspiration was macroscopically visible in only 10% and histologically 30%.

## Emphysema aquosum

In the drowning group, the dome of diaphragm was located at an average level of the fifth anterior rib on the right side (range rib 4–6). The position of the diaphragm in the control group was significantly higher, at the level of the fourth anterior right rib (range rib 4–6) (Table 1). The position of the diaphragm was confirmed at autopsy.

No correlation between retrosternal mediastinal width and degree of emphysema was detected.

The bronchial-arterial coefficient (diameter of bronchus/diameter of pulmonary artery) in drowning cases was 0.84 (Fig. 2), whereas in the control group a significantly higher average of 1.04 was measured (Table 1). This difference was confirmed histologically (Fig. 3): the drowning group had a significantly lower coefficient (0.77) than the control group (0.97); $P$=0.02 (Wilcoxon-test).

The posterior distance between the vocal cords did not show any significant difference between the two groups.

A mosaic pattern of hypo- and hyperperfused lung areas was present in 60% of the drowning cases in both autopsy and MSCT (Fig. 2), but only in 10% of the control cases.

## Heart failure

The CTR did not show a significant difference between the drowning group (0.47) and the control group (0.48). Only 30% of drowning cases showed an enlarged heart at MSCT; 40% at autopsy. The size of the right atrium was increased in 60% of the cases, the size of the right ventricle in 40%, values were 40% and 20%, respectively, at autopsy. In comparison, the control group showed an enlarged right atrium in 70%.

The left heart side was increased in only 10% of drowning in MSCT (one case).

The inferior caval vein was enlarged in 50% of the drowning as well as the control cases.

## Pulmonary edema

Fifty percent of the drowning cases showed pulmonary edema at MSCT, ranging from interstitial to alveolar transsudation. The average weight of both lungs was 983 g at autopsy in the drowning group (range 600–1,600 g). The control group showed wet lungs in only 30% of the cases. Pleural effusion was found in 70% (80% at autopsy) and in

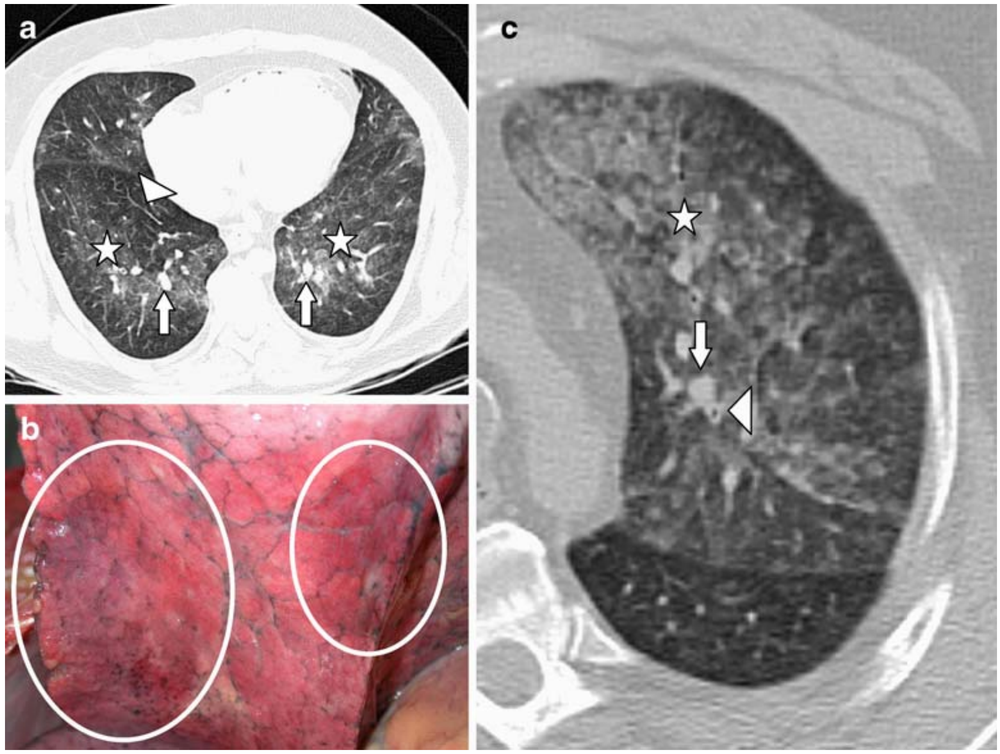


**Fig. 2** **a**–**c** Mosaic pattern of lung perfusion in aspiration. **a**) Hyperperfused lung areas with ground-glass appearance (*asterisks*) and dilated pulmonary arteries (*arrows*) are found in contrast to the hypoperfused lung parenchyma with narrow arteries (*arrowhead*). **b**) Autopsy correlation of the mosaic perfusion with hyperperfused, dark red lung areas (*circles*) and hypoperfused overinflated pale areas. **c**) Hyperperfused upper lobe with hyperdense lung parenchyma (*asterisk*). Note the increased diameter of the pulmonary artery (*arrow*) compared with the accompanying bronchus (*arrowhead*)

only 16% of the control group. Radiologically, 20% of the drowning victims had a plume of froth, which was confirmed at autopsy (Fig. 4).

## Haemodilution

In the drowning cases, an average blood density at the right atrium of 50 HU was found (Fig. 5), whereas the control group showed a significantly higher mean density of 64 HU (Table 1). There was a less significant difference in the left atrium, where the drowning victims had mean densities of 55 HU and the control group 60 HU.

## Distention of stomach and duodenum

The average volume of the stomach in MSCT was 470 ml, ranging from 50 to 1,200 ml (Fig. 6). Autopsy confirmed an average volume of stomach of 480 ml. Interestingly the control group showed only about half of this volume (276 ml, Table 1).

The content of the stomach in the drowning group measured an average of 20 HU and in the control group of 39 HU (Table 1).

In 90% of the drowning cases, a distension of the duodenum by watery content was found. But also the

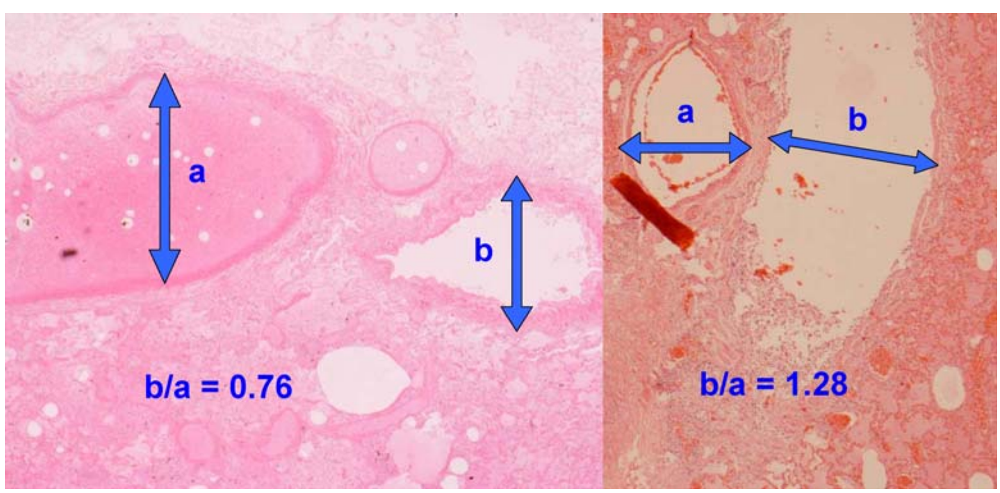


**Fig. 3** On the *left side*, broncho-arterial-coefficient of a drowning case, indicating bronchospasm and/or hyperperfusion (*a* artery, *b* bronchus). Note the emphysema aquosum on top of the picture. On the *right side*, a case of the control group with a higher broncho-arterial coefficient

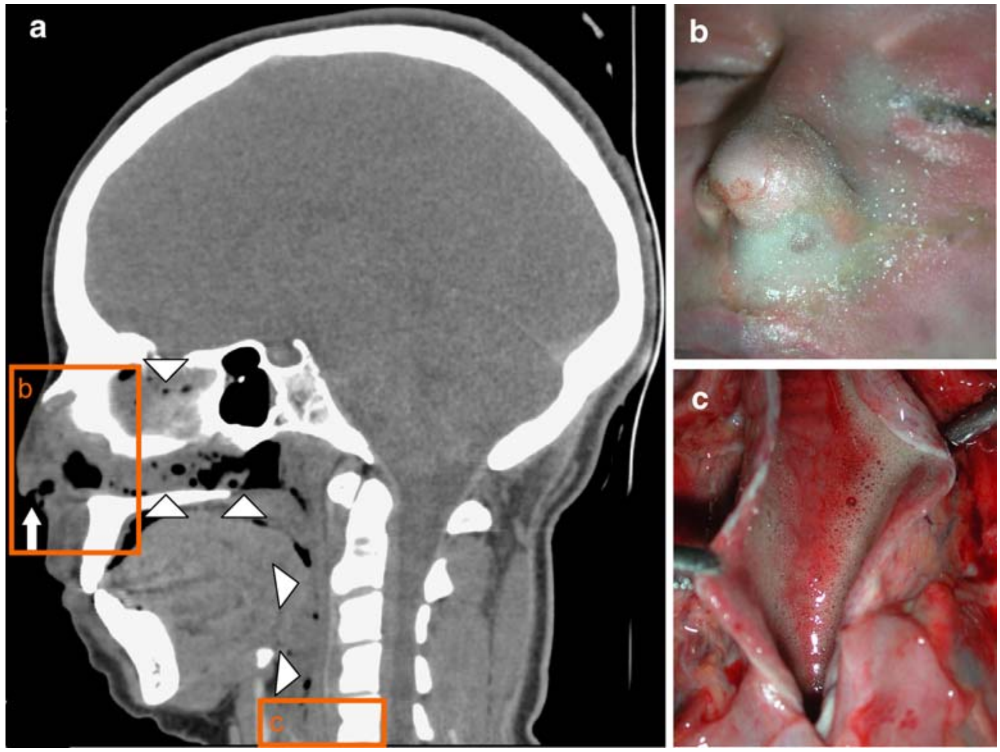


**Fig. 4** **a**–**c** Plume of froth. Sagittal reconstruction of the head at soft tissue window (**a**) and autopsy correlation (**b**, **c**). Froth in the nostrils (*arrow*), upper airways, nasal cavity, pharynx and trachea (*arrowhead*) (**c**)

control group demonstrated a duodenal distension in 60% of the cases (Table 1).

Water in the paranasal sinuses

Every case of drowning presented with fluid in the paranasal sinuses, especially in the maxillary (Fig. 7) and sphenoidal sinuses, both in 100% of cases. The cases of the control group showed these findings significantly less, in only 36% and 18%, respectively (Table 1). Frontal sinuses had a watery content in 70% and ethmoidal sinuses in 80% of drownings, the control group in 18%, and 36%, respectively.

## Discussion

One of the classic findings of drowning at autopsy are Paltau's spots (autopsy revealed this finding in 70% of the drowning cases): the pleural haemoglobin deposits from haemolysis are much too small to be visualised by MSCT. It might be possible that the susceptibility artefacts of haemoglobin in MRI might uncover Paltau's

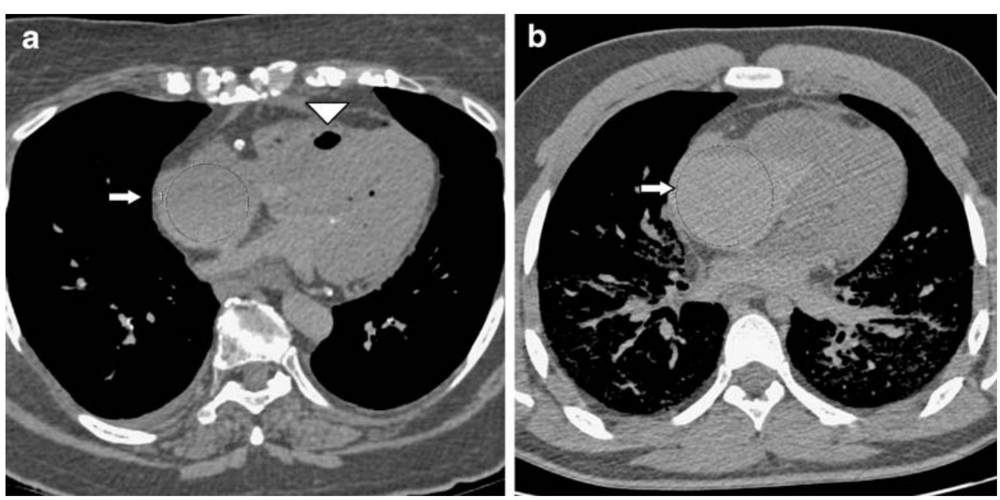


**Fig. 5** **a**, **b** Haemodilution. **a** Measurement of the blood density in the right dilated atrium in a drowning case shows 45 HU, indicating possibly increased water content (*arrow*). Note the additional gas in the right ventricle. **b** A case from the control group presents a "normal", postmortal density of the blood in the right atrium of 70 HU (*arrow*)

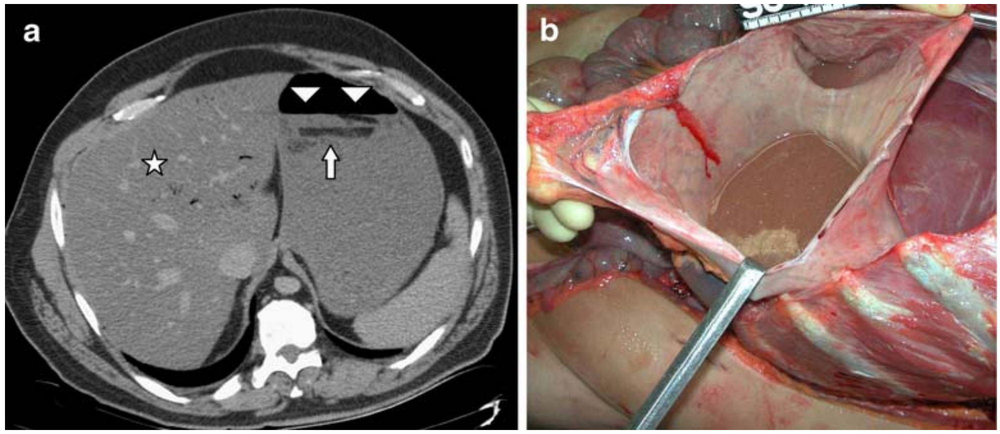


**Fig. 6** **a**, **b** Distention of stomach. **a** Swallowed water in a distended stomach with an air fluid level (*arrowhead*) and alimentary leavings swimming close to the top (*arrow*). Note the hypodense liver indicating fatty liver as an additional finding (31 HU). **b** Autopsy image of the stomach fluid content

spots in special sequences. Further studies on this issue are necessary.

Otherwise we found all the typical forensic signs of "wet" drowning in MSCT, such as aspiration, emphysema aquosum, mosaic pulmonary edema, and distented stomach and duodenum. Additionally we could document and directly measure bronchospasm, water in the paranasal sinuses and haemodilution which is rather complicated or impossible at the classical autopsy.

The pathophysiological hypo- and hyperperfused areas in the lung (mosaic pattern) with narrow or dilated pulmonary arteries is much better visualised in the axial images of the MSCT than during classical autopsy.

The bronchial-arterial coefficient is significantly decreased in the drowning cases in MSCT and histology; it is a sign of bronchospasm and/or water resorption: this coefficient decreases due to a small diameter of the bronchus (bronchospasm) or due to a large arterial diameter, hypothesizing that a ratio of $<0.9$ might reflect drowning.

No standard values exist for post-mortem blood densities (HU). It is rather difficult to measure the accurate density of blood after sedimentation. But measurement of the density in the right atrium with a big region of interest (ROI) shows a significant difference between the drowning and the control group (Table 1): that a blood density below 55 HU is indicative for haemodilution. This level needs to be confirmed in a larger study. The mean blood density in the left atrium of the drowning cases is slightly higher than in the right atrium, probably due to the more dependent location of the left atrium. That is why a decreasing HU gradient between left and right cannot be found.

The size of the right atrium, like the size of the inferior caval vein, although large, do not seem to be specific for drowning, as the control group showed similar data. This is possibly due to the general blood congestion during death.

The amount of water in the lung is rather small because of the quick haemodilution effect of fresh water in the lung. A secondary mosaic pulmonary edema due to bronchospasm with consecutive hyperperfused lung areas is much more specific.

The stomach and duodenum were distended, but interestingly, only the duodenal size of the drowning victims showed a significant difference compared with the non-drowning cases (Table 1). As the aspirated and swallowed fluid in drowning is fresh water, a low density in the stomach is expected despite the admixture with the rather dense contents of the stomach. So the content showed an average density of 20 HU and the normal content of stomach in the control group was 39 HU.

Although the examined findings of drowning are not specific, those combinations such as, e.g., froth in the airways, emphysema aquosum and mosaic patterns of the lung in a victim retrieved from fresh water can serve as highly suspicious for drowning. The differential diagnosis of these findings concerning the cause of death would be *heart failure* with consecutive pulmonary edema and froth in the airways; *adult respiratory distress syndrome*, for instance from aspiration and bilateral *bronchopneumonia* with patchy mosaic-like consolitations. Less probable are

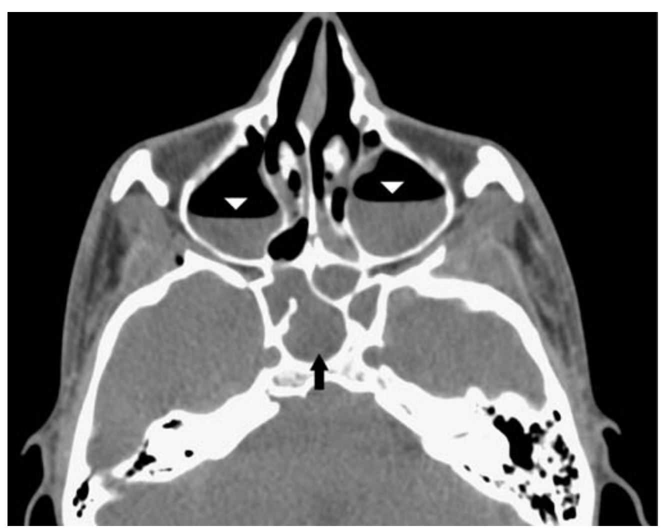

**Fig. 7** Water in the paranasal sinuses on an axial CT image. The maxillary sinuses show air/fluid levels in a drowning victim (*arrowhead*). The sphenoidal sinus is totally filled with fluid (*arrow*)

*vasculitis* with pulmonary haemorrhage and *pulmonary embolism* (multiple, peripheral).

Where in near drowning patients a ground glass pattern is predominant in MSCT, the wet drowning cases show primarily air space consolidation from pulmonary edema and/or aspiration; additionally, near drowning patients do not have emphysema aquosum.

All our cases were exclusively fresh water drowning victims. Since the pathophysiology of drowning in salt water is different, the radiological appearance of the examined signs might deviate from our data. The high osmolality of aspirated salt water is expected to pull water into the lung, leading to substantial lung edema and hypovolemia.

On the other hand, CT provides an objective, compact and distributable documentation of the full body in a non-invasive way with the option of two-dimensional and three-dimensional reconstruction of findings [30, 31].

In conclusion, post-mortem MSCT performed prior to classical autopsy is a useful visualisation and documentation tool in diagnosing death due to drowning. While experience is currently limited, it is too early to predict whether it might replace classic autopsy; more likely, it might allow for a more localized, less destructive autopsy in the future.

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