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ORIGINAL ARTICLE

Can post-mortem CT reliably distinguish between drowning and non-drowning asphyxiation?

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Abstract

Purpose The aim of this study is to evaluate whether previously reported post-mortem CT findings in drowning can reliably distinguish drowning from asphyxiation by any other manner.

Materials and methods Cases (n=14) were corpses with cause of death determined as drowning by concordant autopsy findings and physical and circumstantial evidence. Controls (n=11) were corpses in which the cause of death was defined as asphyxiation by any other manner than submersion in a liquid. Images were evaluated for the presence of fluid in paranasal sinuses, mastoid air cells and lower airways, frothy foam in the upper airways, ground-glass opacity of the lung parenchyma, the height of the right hemi-diaphragm, the interpulmonary distance at the level of the aortic valve, the mean density of intracardiac blood, and gastric and esophageal contents. Descriptive statistics, Fisher's exact test, and Student's t test were used when appropriate.

Results Only the height of the right hemi-diaphragm differed significantly (p=0.045) between cases (mean 5.4) and controls (mean 4.3). Other findings were not significantly different between both groups.

Conclusion Our results indicate that it is not possible to reliably distinguish drowning from non-drowning asphyxiation on CT, because many findings in drowning were also present in non-drowning asphyxiation. CT indicators for drowning as the cause of death should therefore be defined with great caution, keeping in mind that they are not specific to only a single cause of death.

Keywords Asphyxiation · CT · Drowning · Post-mortem imaging

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Introduction

Drowning is defined as asphyxiation caused by submersion in a liquid. Asphyxiation can be defined as a severe hypoxia leading to hypoxemia and hypercapnia, loss of consciousness, and, if not corrected, death. According to the estimated causes of death published by the World Health Organization, 305,929 individuals drowned worldwide in 2008, with 27,216 of these deaths occurring in Europe[1]. In Belgium, in that same year, 77 deaths were stated as the result of drowning on the official declaration of death[2]. Drowning is a difficult cause of death to determine by classical autopsy, because of the non-specific post-mortem findings. Only the presence of diatoms deep in the blood circulation (e.g., bone marrow) is considered, by some, a definite, positive proof of drowning, but the technical procedure to detect these microorganisms is elaborate and delicate, and false-positive results due to contamination can occur. Negative results do not exclude drowning [1]. Other causes of death have to be excluded in order to diagnose drowning with a level of certainty, and circumstantial evidence (e.g., police inquiry, crime scene investigation) might be crucial for the ultimate diagnosis.

[1] Health statistics and informatics Department WHO. Causes of death 2008: summary tables. Geneva, Switzerland, 2011.
[2] FOD Economie Algemene Directie Statistiek en Economische Informatie. Doodsoorzaken 2008: gedetailleerde gegevens. Belgium, 2012.

Obviously, a corpse recovered from water does not automatically imply that death occurred by drowning. There are several possible explanations why a body could end up in the water. The simplest scenario is, of course, drowning: a person is (accidentally or intentionally) submersed in water and asphyxiates. But there are other explanations possible. A person could die from another cause while being in the water (e.g., heart attack during swimming), or a person might die from another cause on land, and end up in the water after death, by forces of nature or by a malicious act of another person.

Drowning is considered an unnatural cause of death and is therefore subject to forensic investigations, typically including a full autopsy. Increasingly, in medico-legal post-mortem examinations, a so-called *virtual* autopsy is used by applying medical imaging techniques to examine a dead body in a non-invasive manner [2]. For this reason, determinants of drowning on post-mortem CT have been examined and proposed in other studies [3, 4]. However, so far, no study has been published comparing drowning with other causes of asphyxiation. The purpose of our study is to answer the question whether these findings are specific to asphyxiation by submersion in a liquid or whether they can be found regardless of the cause of asphyxiation.

Materials and methods

Cases and controls

Over a 2-year time span, we evaluated post-mortem CT scans requested for medico-legal purposes in the Department of Radiology at Antwerp University Hospital. The case inclusion criterion was body recovered from water, with cause of death determined as drowning by concordant autopsy findings, physical evidence, and circumstantial evidence. This allowed us to include 14 cases in our study. The control inclusion criterion was body in which the cause of death was defined as asphyxiation by any other manner than submersion in a liquid. For example, we included cases of strangulation, compressive asphyxia, positional asphyxia, choking, and smothering. This allowed us to include 11 controls. Informed consent by next of kin was not required since the investigation was part of a public inquiry.

Equipment

All scans were obtained on a 64-slice multi-detector CT (GE LightSpeed, General Electric, Milwaukee, WI, USA), with acquisition of a volumetric whole body scan. Images were reconstructed in soft tissue windows, bone windows, and lung windows, and multiplanar and volumetric reconstructions were obtained as needed. Measurements and evaluations were performed on a regular clinical PACS workstation using the manufacturer's software (Advantage Windows, General Electric). Scan acquisition and image construction parameters are summarized in Table 1.

Measurements and evaluations

The following CT findings were evaluated: presence of fluid in the paranasal sinuses (FPS), fluid in the mastoid air cells (FMA), fluid in the lower airways (FLA), frothy foam in the upper airways (FFUA), ground-glass opacity of the lung parenchyma (GGO), the level of the right hemi-diaphragm (LRHD), the interpulmonary distance at the level of the aortic valve (IPD), the mean density of intracardiac blood (MDCB), the mean density of gastric contents (MDGC), and the mean density of esophageal contents (MDEC). The rationale behind these evaluations will be explained under "*Results*."

All scans were evaluated by two radiologists in consensus, according to a scoring system with dichotomous scoring, ordinal scoring, or averaging of three measurements, depending on the type of finding (Table 2).

Statistics

All statistical tests were performed using IBM SPSS Statistics 20. Descriptive statistics included calculation of frequencies for the dichotomous values (FPS, FMA, FFUA, FLA, GGO) and calculation of means and standard deviations for the ordinal and continuous variables (LRHD, IPD, MDICB,

Table 1 Scan parameters

Parameter	Skull	Thorax	Abdomen
kV	120	120	120
mAs	300	50–300	50–300
Collimation	40 mm	40 mm	40 mm
Pitch	0.531	1.375	1.375
Slice thickness	3 mm	3 mm	5 mm
Field of view	Head (320 mm)	Large (500 mm)	Large (500 mm)
Kernel	Standard (head)	Standard (soft) and lung	Standard (soft)
Image matrix	512×512	512×512	512×512

Table 2 Scoring system

Finding	Evaluation	Type of variable	Variable input
Fluid in the paranasal sinuses	Present or absent	Dichotomous	1 or 0
Fluid in the mastoid air cells	Present or absent	Dichotomous	1 or 0
Fluid in the lower airways	Present or absent	Dichotomous	1 or 0
Frothy foam in the upper airways	Present or absent	Dichotomous	1 or 0
Ground-glass opacity of the lung parenchyma	Present or absent	Dichotomous	1 or 0
Position of the right hemi-diaphragm	Nearest anterior rib level to a tangential line through the dome of the diaphragm, perpendicular to the length axis of the torso	Ordinal	1 through 12
Interpulmonary distance at the level of the aortic valve	Mean of three measurements, expressed in millimeters	Continuous	Value (mm)
The mean density of intracardiac blood	Mean of three measurements, ROI placement in the middle of the right atrium, expressed in Hounsfield units	Continuous	Value (HU)
Mean density of gastric contents	Mean of three measurements, ROI placement in the middle of the stomach, expressed in Hounsfield units	Continuous	Value (HU)
Mean density of esophageal contents	Mean of three measurements, ROI placement at the level of the carina, expressed in Hounsfield units	Continuous	Value (HU)

MDGC, MDEC). Normality of distribution was evaluated using the Shapiro-Wilk test and Q-Q-plots.

Fisher's exact test and Student's *t* test were used to examine the significance of the differences. Significance was set at $p<0.050$.

Results

The results are summarized in Table 3, with frequencies or means and standard deviations (positive and negative) when appropriate, the significance of the difference between groups, and the applied statistical test.

In drowning, inflow of fluid into the paranasal sinuses and mastoid air cells and the lower airways has been described [5]. Whether this occurs actively through aspiration, or passively in prolonged submersion, is subject of debate, but not relevant to our study. We simply evaluated the presence or absence of fluid in the paranasal sinuses, the mastoid air cells (Fig. 1), and the lower airways (Fig. 2). We found no significant differences between our cases and controls; on the contrary, one finding was even more frequent in our controls than in our cases (fluid in the mastoid air cells), though not significantly so.

Another important element in the diagnosis of death by drowning is the formation of frothy foam [5], which is due to interaction of the submersing liquid with air and proteinaceous contents of the airways (Fig. 3). To our surprise, frothy foam was found more frequently in controls than in cases, although this difference was not statistically significant, probably due to the small number of cases.

Table 3 Results

Finding	Cases	SD	Controls	SD	p value	Test
Fluid in the paranasal sinuses	93 % (n=14)	–	78 % (n=9)	–	0.538	Fisher's exact test
Fluid in the mastoid air cells	14 % (n=14)	–	20 % (n=10)	–	1.000	Fisher's exact test
Frothy foam in the upper airways	8 % (n=14)	–	36 % (n=11)	–	0.133	Fisher's exact test
Fluid in the lower airways	86 % (n=14)	–	67 % (n=9)	–	0.343	Fisher's exact test
Ground-glass opacities	90 % (n=10)	–	89 % (n=9)	–	1.000	Fisher's exact test
Position of the right hemi-diaphragm	5.4 (n=7)	1.1	4.3 (n=9)	0.9	0.045	Student's *t* test
Interpulmonary distance (mm)	8.9 (n=7)	19.1	17.0 (n=4)	21.5	0.531	Student's *t* test
Mean density of intracardiac blood (HU)	61.9 (n=6)	12.5	57.1 (n=7)	13.3	0.524	Student's *t* test
Mean density of gastric contents (HU)	15.9 (n=10)	14.9	13.1 (n=9)	22.1	0.746	Student's *t* test
Mean density of esophageal contents (HU)	−111.5 (n=14)	249.3	−33.3 (n=9)	119.5	0.417	Student's *t* test

n=sample size

Fig. 1 Post-mortem para-axial CT scan through the base of the skull and paranasal sinuses. There is fluid in both paranasal sinuses (*white arrows*), with air-fluid levels, as well as in the tympanic cavity and mastoid air cells on the right (*black arrow*)

Ground-glass opacities are a common pathophysiological finding in many pulmonary afflictions, and they have also been described in near-drowning and drowning [6] (Fig. 4). In our study, intrapulmonary ground-glass opacities were the most frequent finding on post-mortem multi-detector CT scans, and there was no significant difference between both groups, underlining the fact that this is also a very non-specific finding.

To evaluate the so-called emphysema aquosum [5], a state of hyperinflation of the lungs caused by a one-way-valve type obstruction of the upper airways, we used two measurements, which we believe to be an indirect evaluation of hyperinflation of the lungs. The first is the anterior interpulmonary distance (Fig. 4), which is a reflection of approximation of the lungs anteriorly at the midline, with overlap occurring in frank hyperinflation. The second is the anterior rib level of the right hemi-diaphragm (Fig. 5), because hyperinflation causes a relatively lower position of the diaphragm. The usage of the right hemi-diaphragm instead of the left is of course debatable. We chose right for a number of reasons. First of all, to be consistent, we did not wish to switch between left and right between cases. Secondly, since the position of the right hemi-diaphragm is less flexible than the left, we expected less variance in measurements. The anterior interpulmonary distance did not differ significantly between cases and controls, due to overlapping results and variance, as reflected in the standard deviations. However, the anterior rib level of the right hemi-diaphragm did differ significantly between both groups (p=0.045), even though the difference was only approximately one rib level. Because the absolute difference is small, it is very questionable whether this finding is useable in the determination of cause of death.

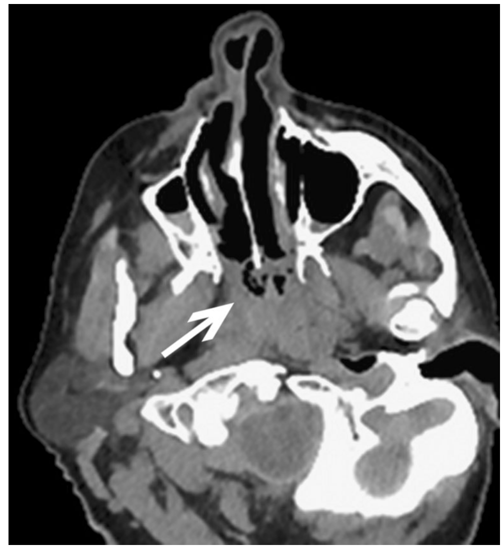

Fig. 3 Post-mortem para-axial CT scan through the nasal cavity demonstrating frothy foam in the upper airways (*white arrows*) and also fluid in the paranasal sinuses

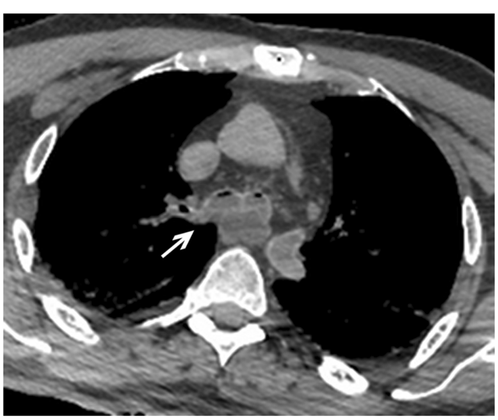

Fig. 2 Post-mortem axial CT scan of the chest, at the level of the carina, in mediastinal window. The right and left main stem bronchi and the esophagus are partially filled with fluid (*white arrow*)

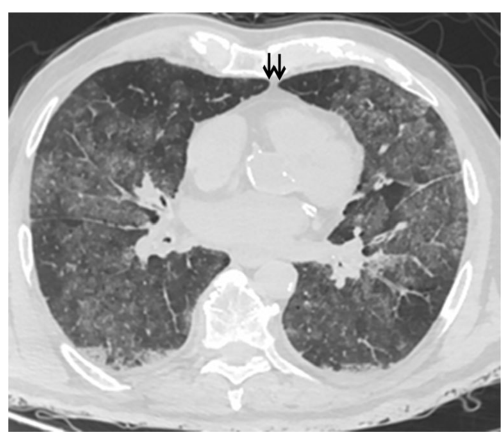

Fig. 4 Post-mortem axial CT scan of the chest in lung window, demonstrating ground-glass opacities and interpulmonary distance (*black arrows*)

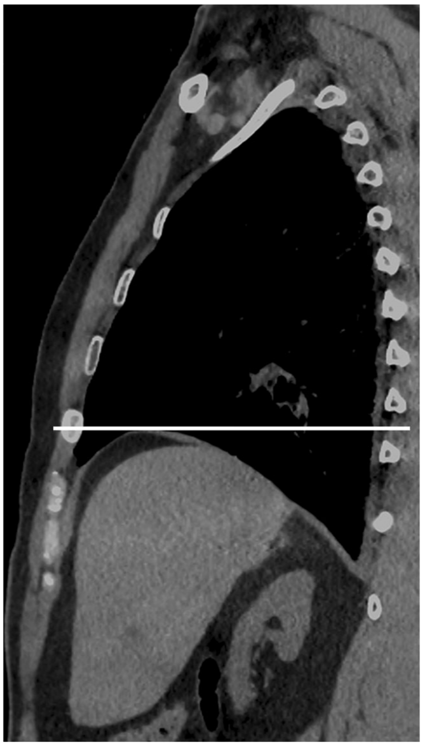

Fig. 5 Post-mortem sagittal CT scan of the chest in mediastinal window, demonstrating the anterior rib level of the right hemi-diaphragm

Aspiration of fresh water in vivo causes a state of hemodilution because of the differences in osmolality between blood and fresh water [5, 6]. All of our cases were recovered from fresh water, so we measured the density of the intracardiac blood in the right atrium (Fig. 6), to evaluate if indeed there was a significant drop in density due to dilution with water. The mean density of the intracardiac blood was on the contrary slightly higher in cases than in controls, but this was a non-significant finding.

It is postulated in forensic literature that drowning often induces swallowing (typical or active drowning) or occasionally passive inflow of water into the upper gastrointestinal system, although the latter is extremely rare [5]. In this light, we evaluated the density of the gastric (Fig. 7) and esophageal contents (Fig. 6), according to the hypothesis that the density of the contents will drop due to mixing with low density fluids in drowning. Again, we found no significant difference between our cases and controls, probably due to the large overlap and variance, as reflected in the standard deviations. Note that the esophageal "region of interest" (ROI) placement often yielded negative Hounsfield units, because of the frequent presence of air in the esophagus.

In short, only the mean height of the right hemi-diaphragm differed significantly (p=0.045) between cases (mean of 5.4) and controls (mean of 4.3). For all other parameters, there were no statistically significant differences between both groups.

Discussion

Many of the controls showed multiple signs previously associated with drowning. Some of our results suggest that these findings are rather specific to asphyxiation instead of drowning alone, or even not specific at all. Prior studies that postulated these findings as indicative of drowning have one thing in common: they did not compare drowning with other manners of asphyxiation, but with completely different mechanisms of death, e.g., lethal brain injury [3] and sudden coronary death [4]. A third study compared the presence of fluid in the paranasal sinuses in drowning and in a whole range of causes of death, including a small number of asphyxiation cases. The authors also concluded that the presence of these signs had a low positive predictive value [7]. However, they did state that the absence of these findings could exclude drowning, with a high negative predictive value.

On the other hand, we evaluated only the absolute presence or absence of findings, and we did not quantify in any other way. Perhaps the magnitude of certain findings is better

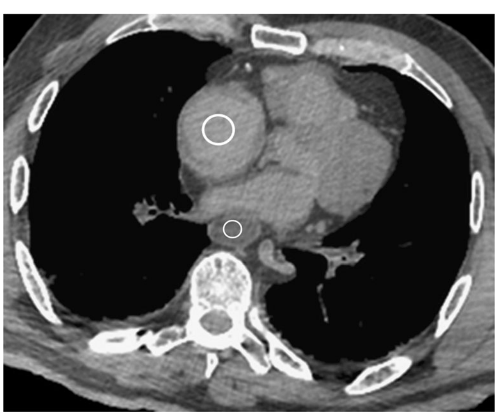

Fig. 6 Post-mortem axial CT scan of the chest in mediastinal window, demonstrating the placement of ROI's for measuring the density of the intracardiac blood and esophageal contents

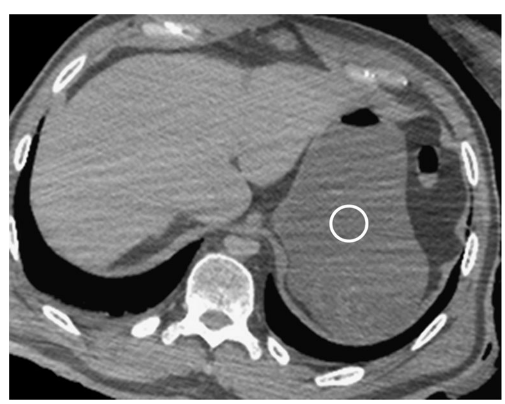

Fig. 7 Post-mortem axial CT scan of the upper abdomen in parenchymal window. The ROI placement for measuring the density of the gastric contents is indicated

related to drowning, as is suggested in a study by Kawasumi et al. [8].

Another question we asked ourselves is whether certain findings are the result of *active drowning* or merely the result of a prolonged stay in the water, with passive mechanisms at work. This, however, could not be evaluated in the present study, and a different study design would be necessary.

This limited study is subject to several criticisms. First of all, our study suffers from the small number of cases, a limitation often encountered in forensic imaging research. This makes it difficult to obtain relevant, reliable, and statistically significant results and is the first and foremost reason why further research in this area is necessary and should be supported with larger studies.

Secondly, we encountered practical problems of an entirely different nature: not all bodies were intact at the time of scanning and some were in a more or less advanced stage of decomposition. For this reason, we had to perform case per case exclusion for some CT findings (e.g., when only half a torso was recovered from water after post-mortem severing by a ship's propeller and the gastric and esophageal content could not be evaluated). These practical limitations are the main reason for the missing variables and smaller sample sizes for some findings. Even so, our results should incite discussion.

In conclusion, we were not able to identify a reliable and useable *tell-tale sign* of drowning on post-mortem multi-detector CT when we compared the findings with non-drowning asphyxiation. To ascertain that drowning is the cause of death in a body found in water, we need to draw on multiple sources of evidence. Certain CT findings can be supportive of the diagnosis of drowning in a body recovered from water, but there is considerable overlap between the CT features of drowning and non-drowning asphyxiation. Post-mortem CT has the advantage of evaluating anatomical areas not visualized in classic autopsy and thus providing additional information to the forensic investigation. Another advantage is it being a non-invasive investigation, requiring no incisions or stitches.

Ethical standards The experiments comply with the current laws of the country in which the research was performed and with institutional regulations.

Conflict of interest The authors declare they have no conflict of interest.

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