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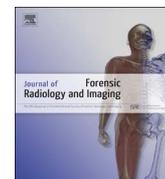
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Drowning investigated by post mortem computed tomography and autopsy



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ABSTRACT

Case control study of drowning fatalities investigated with autopsy and post mortem computed tomography (PMCT). 40 drowning fatalities (25 men, 15 women; 24 salt water, 16 fresh water) and 80 controls were included. The aim was to investigate the difference in lung tissue density (g/liter) and radio opacity between drowning cases compared to control cases and to determine if it was possible to differentiate saltwater and freshwater drowning by measuring a difference in radio density of blood in the heart chambers or great vessels before and after passage through the lungs of a drowned individual or when comparing drowned individuals with controls. The lung density was measured by a combination of PMCT measured total lung volume and autopsy measured total lung weight. We found that the lung density and the lung radio density were decreased, the lung volume increased and the lung weights equal in drowning cases compared to controls, illustrating the phenomenon known as “emphysema aquosum”. The physiological explanation could be washing out of surfactant by the drowning media, resulting in atelectasis and trapping of air in the peripheral lung regions. It was not possible to separate fresh and saltwater drowning by comparing radio opacity of blood in the heart chambers or great vessels or by comparing the radio opacity of blood in cases and controls. We suspect that sedimentation of red blood cells after death makes such measurements meaningless.

1. Introduction

The introduction of post mortem computed tomography (PMCT) as an adjunct to autopsy in many forensic institutes [1–3] has made it possible to easily obtain information about volumes and radio densities.

We have investigated some aspects of how these PMCT measurements can be used in drowning cases.

One would intuitively expect that the density of the lungs measured in, e.g., grams per litre, and the total lung radio density measured in Hounsfield units (HU) would increase when an individual drowns. Water is, after all, aspirated through the airway into the lungs, except in the minority of so-called dry drownings. We decided to test this assumption by measuring the density and radio density of the lungs with post mortem computed tomography (PMCT) and autopsy.

We also sought to investigate whether it was possible to differentiate saltwater and freshwater drowning by measuring differences in the radio densities of the blood in the heart chambers or great vessels before and after passage through the lungs of a drowned individual or when comparing drowned individuals with controls.

The study was thus based on the following research questions:

1. Is there a difference in lung tissue density, as calculated from lung

volume measured by PMCT and lung weight measured at autopsy, between drowning cases and control cases?

2. Is there a difference in total lung radio density between drowning cases and control cases?

3. Is it possible to differentiate saltwater and freshwater drowning by measuring differences in the radio densities of blood in the right and left ventricles or in the pulmonary trunk and the aorta or by comparing the radio densities of blood in drowning cases and controls?

2. Material and methods

This was a retrospective case-control study of victims of drowning and controls who were autopsied and CT-scanned at the Department of Forensic Medicine of the University of Southern Denmark from 2006 to 2015. The department provides forensic services for the approximately 1 million inhabitants of Southern Denmark. This region has many beaches and also many lakes and rivers. Only individuals who drowned outdoors in salt- or freshwater were included.

The control group was selected as the first age- and gender-matched individuals who were autopsied and CT-scanned before and after each case. Individuals with severe thorax injuries, severe decomposition, and children under 16 years were excluded from the study.

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Table 1
Scan protocol used for PMCT of the thorax.

mA	kV	Slice	Collimation	Pitch	Rotation time	Kernel
60	130	5 mm	2.5 mm	1.8	1.0 s	Median smooth B31 and High res B70

Imaging was performed immediately before the autopsy. The scanner was a Siemens Somatom Spirit dual-slice CT scanner. The scanning protocols are summarized in Table 1. Contrast was not used and post mortem ventilation was not performed. The bodies were scanned naked, without metallic objects and with the arms fixed above the head while scanning the thorax. Lung tissue density was calculated in grams/litre based on the volume and weight of the lungs. The volume was calculated from the PMCT using the grow region tool in the Osirix 7.0 software to identify the total lung volume as the region of interest (ROI). The lung weight was measured at autopsy on a calibrated Saltzer weight after the bronchial system had been cut open and with each lung separated from the trachea. Total lung radio density was measured in Hounsfield units (HU) from the ROI identified in Osirix. Blood radio density was measured in HU in the right and left ventricles and in the pulmonary trunk and the ascending aorta using the Osirix 7.0 software. The measurements were taken from a transverse slice of the midsection of the ventricle or vessel in question, and with a ROI that was as large as possible without including the wall. One observer, who had been trained by an expert in forensic medicine with experience in forensic radiology, performed all measurements. The data were entered into a computer database (SPSS Statistics version 23). A paired Student's t-test was used to compare the means, and p-values below 0.05 were taken as significant.

3. Results

The study included 40 victims of drowning (25 men, 15 women; 24 salt water, 16 fresh water) and 80 controls (50 men, 30 women). All cases were registered as wet drowning based on a subjective estimation made by the pathologist. The average age in both case and control group were 55 years (SD 17 years).

There were no statistical significant difference in average body weight or length between cases and controls (weight and length: 75 kg/77 kg and 173/174 cm respectively).

The average lung volumes of drowning victims were significantly larger, the lung densities significantly smaller, and the average lung weights equal relative to the control group (Table 2). The average lung radio densities, as measured in HU, were significantly lower in the drowning cases than in the control cases.

The average radio densities, measured in HU, of the blood were higher in the left ventricle and ascending aorta than in the right ventricle and the pulmonary trunk in both the salt- and freshwater drowning cases and in the controls, with no significant differences

Table 2
Drowning cases and controls that were CT-scanned and autopsied 2006 – 2015 in Southern Denmark. Measurements of average lung weights, volumes, density and radio densities.

		N	Mean	Standard deviation	Statistical significance
Lung weight (grams)	Case	40	1337	324	NS
	Control	80	1377	415	
Lung volume (cm ³)	Case	40	3136	754	P < 0.05
	Control	80	2556	874	
Lung density (gram/l)	Case	40	448	141	P < 0.05
	Control	80	594	249	
Lung radio density (HU)	Case	40	-1073	258	P < 0.05
	Control	80	-925	352	

Table 3
Average Hounsfield units (and standard deviation) of the blood before and after the lungs (right/left ventricle and pulmonary trunk/ascending aorta) in freshwater drowning, saltwater drowning and controls.

		HU		HU
Freshwater (N=16)	Right ventricle	35 (SD 11)	Left ventricle	50 (SD 11)
	Pulmonary trunk	52 (SD 18)	Ascending aorta	62 (SD 9)
Saltwater (N=24)	Right ventricle	40 (SD 18)	Left ventricle	51 (SD 13)
	Pulmonary trunk	54 (SD 18)	Ascending aorta	68 (SD 9)
Controls (N=80)	Right ventricle	44 (SD 15)	Left ventricle	50 (SD 8)
	Pulmonary trunk	53 (SD 20)	Ascending aorta	65 (SD 14)

between these three groups (Table 3).

4. Discussion

In textbooks, the lungs of drowning victims are described as overinflated, sometimes to such a degree that impressions of the ribs may be seen in their lateral parts, and they exhibit a pale and crepitant texture. The cut surface is usually wet with foamy fluid. This situation has been called “emphysema aquosum” because of its likeness to asthma [4]. Christie et al. [5] described a lower position of the diaphragm on PMCT in drowning fatalities compared with a control group. Our study demonstrated that the extent to which the lungs are over-inflated could be calculated from the PMCT and autopsy findings. We found that the average lung density was lower in the drowning cases compared with the non-drowned controls. To our knowledge, this is the first time that this phenomenon has been measured and expressed as lung density. The physiological explanation could be the washing out of surfactant by the drowning media, which would result in atelectasis and the trapping of air in the peripheral lung regions [6]. It has also been suggested that bronchial constriction induced by aspiration of the drowning fluid may cause expiratory obstruction and hyperinflation [7]. Sogawa et al. [8] found a statistic and significant cut-off value for lung volume that distinguished death by drowning from sudden cardiac death in a study that included 12 drowning cases. We did not find a cut-off value due to an overlap of volume measurements between the cases and controls. Usui et al. [9] described the chest CT image patterns that can be observed in drowning cases and demonstrated that there are significant differences in lung CT numbers that depend on the type of pattern. In experiments with rabbits, Hideki et al. [10] demonstrated ground glass opacity in CT images of the lungs of salt and fresh water drowning and decreased percentages of aerated lung volumes compared to the ante mortem images but found no difference between fresh and salt water. In our study, we did not attempt to make comparisons based on image patterns. A possible source of error could be differences in the distribution of inner livores [11] between cases and controls. The inner livores or hypostasis are a result of sedimentation of red blood cells, and it is possible that drowning death, due to the movement of the body in the water, will have no inner livores in the lungs. We do, however, not believe that this would influence our results since the HU values were measured with the whole lung volume as ROI. This interesting aspect will however be investigated in a separate study.

Animal experiments [6] have revealed different pathophysiologic findings between drownings in salt-water and fresh-water. In fresh-water, aspirated hypotonic fluid passes into the blood creating fluid overload and haemodilution, whereas the aspiration of salt-water

causes the fluid to be drawn into the alveoli creating pulmonary oedema and haemoconcentration. In fresh water drowning, the influx of hypotonic fluid from the alveoli into the pulmonary circulation may even cause haemolysis with the release of haemoglobin causing differential staining of the intima of the aortic root compared to the pulmonary trunk [12].

However, in many drowning accidents, the volume of aspirated fluid is not sufficient to cause clinically significant effects on blood volume or electrolyte concentration [13], and the cause of death is hypoxemia caused by intrapulmonary shunting, bronchospasm, decreased lung compliance, atelectasis and ventilation-perfusion mismatch. We measured the radio densities of the blood in the right and left heart chambers and in the pulmonary trunk and ascending aorta to determine whether there were any signs of haemodilution or haemoconcentration in freshwater and saltwater cases by calculating the difference in the radio densities of the blood in the right and the left sides of the heart. We assumed that haemodilution would decrease, and haemoconcentration would increase the radio density of the blood measured in HU. Moreover, we suspected that there might be a difference between the radio densities of the blood in the right and left sides of the heart in individual drowning victims because by passing through the lungs, the blood would become either diluted in fresh water drowning cases or concentrated in salt water drowning cases. However, this pattern was not found. There were significantly higher HU values in the left ventricle and ascending aorta than in the right ventricle and pulmonary trunk, respectively, in all groups (i.e., fresh and salt water drowning and controls), but there were no statistically significant differences between the groups. Christe et al. [5] investigated 10 fresh water drownings and compared them with 20 non-drowned individuals. These authors found that the average radio densities of the blood in the right atria of the drowned cases was significantly lower than that in the controls (50 and 64 HU, respectively) and concluded that a blood radio density below 55 HU in the right atrium was indicative of haemodilution. However, these authors did not find a similar difference for the left atrium and did not attempt to compare the right and left atria of the drowned individuals. Ambrosetti et al. [14] found a lower blood radio density in the left ventricle compared to the right in a series of 6 fresh water drowning cases. These authors also found lower radio densities of the blood in all heart chambers in drowning cases compared with 16 non-drowned individuals. Based on our results, we believe that it is impossible to determine haemodilution or haemoconcentration after death by measuring radio density of blood. The left ventricle and the ascending aorta are situated lower in the body in the supine position than the right ventricle and the pulmonary trunk, and it is possible that the differences in the HU values of the blood that we found simply reflect the sedimentation of red blood cells after death.

5. Conclusion

The lung density (g/litre) measured by a combination of the PMCT-measured total lung volume and the autopsy-measured total lung weight is decreased in drowning cases as a result of emphysema aquosum. 2. It is not possible to separate fresh and saltwater drowning cases by comparing the radio densities of the blood in the heart chambers or the great vessels or by comparing the radio densities of blood between cases and controls.

Bullet points 1

Major findings

- Lung volumes of drowning victims are larger than controls.
- Lung weights of drowning victims are equal to controls.
- Lung densities (g/litre) of drowning victims are smaller than controls.
- Lung radio density is lower in drowning victims than in controls.
- There were no differences in radio densities of blood between salt- and freshwater drowning cases and controls.

Bullet points 2

Lung overinflation, so called emphysema aquosum, can be calculated from the PMCT and autopsy findings.

The lung density (g/litre) is decreased in drowning cases as a result of emphysema aquosum.

It is not possible to separate fresh and saltwater drowning cases by comparing the radio densities of the blood in the right and left side of the heart.

It is not possible to separate fresh and saltwater drowning cases by comparing the radio densities of blood between cases and controls.

It is possible that differences in HU values of the blood between right and left heart chamber reflect the sedimentation of red blood cells after death.

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