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ORIGINAL ARTICLE

Postmortem computed tomographic features in the diagnosis of drowning: a comparison of fresh water and salt water drowning cases

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Abstract

Purpose To investigate the effectiveness of postmortem computed tomography in the diagnosis of drowning, focusing on the comparison of fresh water and salt water cases using three-dimensionally (3D) reconstructed data.

Materials and methods We examined features of drowning in 25 fresh water drowning cases (FWDCs; 13 men, 12 women; mean age 73.1 years; range 43–95 years), and compared these with 12 salt water drowning cases (SWDCs; 5 men, 7 women; mean age 66.0 years; range 55–77 years). Pulmonary opacities, volume and density (CT number) of accumulated fluid in the paranasal sinuses and central airways, volume of the stomach/stomach contents, and cardiac blood density were examined.

Results In SWDCs, pulmonary ground-glass opacities with wholly thickened interstitium was frequently identified ($P=0.0274$). Whereas in FWDCs, a significantly larger volume and lower density of fluid in the paranasal sinuses ($P=0.0195$ and $P=0.0104$, respectively), lower density of fluid in the central airways ($P=0.0077$), lower stomach content density ($P=0.0216$), lower density in the left atrium ($P=0.0029$), and a difference of density between the atria ($P=0.0247$) were observed.

Conclusions A lower density in the left atrium was observed in FWDCs compared to SWDCs. This finding may be helpful in differentiating between FWDCs and SWDCs.

Keywords Postmortem CT · Drowning · Ground-glass opacity · CT number · Hemodilution

Introduction

Drowning is among the leading causes of death worldwide, claiming the lives of approximately 372,000 people each year [1]. Recently, the use of postmortem computed tomography (PMCT) for diagnoses in forensic science has increased. Whole-body PMCT, used in previous drowning cases [2–4], revealed that this imaging method is a useful visualization and documentation tool in the diagnosis of death due to drowning [2]. PMCT findings in organs, including the lungs and paranasal sinuses, have been investigated in detail [5, 6]. Of those, lung features (opacities in the lung) have been classified into three major types: Type 1, Type 2, and Type 1 + 2 [5]. PMCT findings in the paranasal sinuses (maxillary and sphenoidal sinuses) revealed a significant difference in volume and density of fluid between drowning cases and controls [6]. PMCT is considered to be an important tool for diagnosing drowning, especially because the Japanese autopsy rates, which are 2% for all deaths and 11.2% for unusual deaths, are both lower than those in other developed countries [7, 8]. Additionally, PMCT can provide information that is difficult to obtain from an autopsy, such as an objective assessment of the severity of pulmonary edema [5]. One of the interesting aspects of PMCT in drowning is the comparison of findings between fresh and salt water drowning cases; a previous study, which investigated findings in the paranasal sinuses, revealed that fluid

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density is higher in salt water drowning cases than in fresh water drowning cases [9]. In another study, the lungs were investigated in a drowning model using New Zealand White rabbits, and it was revealed experimentally that there were no differences among fresh water and salt water drowning cases [10].

Regarding PMCT findings in fresh and salt water drowning cases, comparisons in multiple organs including the airways, stomach, and heart have not yet been conducted, to our best knowledge. Therefore, we performed comparisons of findings within these organs. We also compared findings within the paranasal sinuses to the results reported in the previous study [9]. To the best of our knowledge, there have been no lung comparisons conducted in human drowning cases; thus, in the current study, we compared the lungs in fresh water and salt water drowning cases.

In previous studies of PMCT in drowning cases, most organs (except the paranasal sinuses [6]) such as the central airway, stomach, and heart have been analyzed using only two-dimensional data (linear measurements: width, height, and depth) [2, 4]. In our experience, it is difficult to obtain accurate numerical data from a two-dimensional image. The importance of 3D data or numerical data has been suggested in a previous study [11]. Therefore, in the current study, PMCT findings in drowning cases were examined using three-dimensionally reconstructed (3D) data, not only for the paranasal sinuses, but also for the central airway, stomach, and heart (the lungs were examined without 3D data because their patterns of shadows were examined, rather than numerical data).

Materials and methods

Subjects and overview

This retrospective study was approved by the appropriate institutional review board, which waived the requirement for informed consent owing to the nature of the study. The study was conducted in accordance with the guidelines for the protection of personal information during research in legal medicine. In total, 1145 cadavers underwent simultaneous PMCT (in which all findings were interpreted by radiologists) and forensic autopsy at our institution between June 2010 and April 2017. Amongst these subjects, 278 were considered to have died from drowning (including questionable drowning). Subjects who had died over 48 h before autopsy and those exhibiting significant decomposition ($n=50$) were excluded. Subjects with remarkable external injury ($n=11$), cases of questionable drowning ($n=67$), and those with insufficient information or imperfect CT data sets ($n=44$) were also excluded. Cases of drowning during a bath ($n=12$) were also excluded, as circulatory system diseases may represent the primary underlying pathology in such cases [12]. In some instances, we encountered cases of drowning, in which cardiopulmonary resuscitation (CPR) was performed or suspected before the confirmation of death ($n=54$). These cases were strictly excluded because performing CPR may result in bodily changes that can alter postmortem computed tomography (PMCT) findings. Only cadavers found in the water were selected, while those found near the water ($n=9$) were excluded, as the cause of death may not have been drowning in these cases. All subject exclusions were performed after reviewing police documents and autopsy reports, and totally 241 cases were excluded because of overlapping of exclusion criteria, such as the administration of CPR and insufficient information. After applying the exclusion criteria, 25 fresh water drowning cases (FWDCs; 13 men, 12 women; mean age 73.1 years; range 43–95 years) and 12 salt water drowning cases (SWDCs; 5 men, 7 women; mean age 66.0 years; range 55–77 years) were obtained, and the PMCT findings of these two groups were compared. The places where the victims were found are presented in Table 1. All the subjects in the SWDC group were found in the sea. All PMCT scans in the present study were obtained within 48 h from the presumed time of death.

The mean post-mortem interval to autopsy was 1.35 ± 0.43 days in the FWDCs and 1.13 ± 0.43 days in the SWDCs (Mann–Whitney U test, $P=0.1847$). All autopsies were performed by two board-certified forensic scientists. At the autopsies, white frothy fluid in the respiratory system (including foam around the nostrils) and overexpanded and edematous lungs (emphysema aquosum) were the essential findings that led to the diagnosis of drowning. However, an analysis of the nature of blood in the cardiac cavities was not performed.

For the investigation of cardiac atrial CT numbers, control subjects were consecutively selected from the remaining 867 cases after the selection of drowning cases. The exclusion criteria were almost the same as those used for drowning cases (for details, please see Online resource 1, or ESM 1). Of the excluded cases, some were excluded due to multiple reasons. Consequently, 24 subjects (15 men, 9

Table 1 Places where the fresh water drowning subjects were found ($n=25$)

Place	No. of subjects (%)
River	10 (40.0%)
Irrigation ditch	7 (28.0%)
Pond	4 (16.0%)
Canal	2 (8.0%)
Swamp	1 (4.0%)
Water storage tank	1 (4.0%)

women; mean age 60.3 ± 20.7 years; age range 22–89 years) were included in the control group. The causes of death in the control group are presented in Table 2.

CT scanning (parameters) and three-dimensionally reconstructed data (3D data)

Head-only (series 1) and head-lower extremities (series 2) PMCT images were obtained using an ECLOS scanner (16-row multidetector CT, HITACHI Medical Corporation, Tokyo, Japan). Series 1 images were obtained using the following parameters: 120 kV; 200 mA; scan time, 2 s; collimation, 16 mm × 0.625 mm; reconstructed slice thickness, 5.0 mm. Series 2 images were obtained using the following parameters: 120 kV; 225 mA; scan time, 0.8 s/175 mA; scan time, 0.8 s (head–pelvis/lower extremities); collimation, 16 mm × 1.25 mm; reconstructed slice thickness, 2.5 mm. No contrast medium was administered. To more precisely evaluate changes in the lung parenchyma, we also obtained thin-section CT images with a slice thickness of 1.25 mm using a volume analyzer equipped with an edge-strengthened algorithm (SYNAPSE VINCENT, FUJIFILM Corporation, Tokyo, Japan). To evaluate bodily regions other than the lungs, we obtained reconstructed CT images with a slice thickness of 2.5 mm. For all analyses, slice thickness was determined based on the standard parameters used in the interpretation of PMCT data (2.5 mm for head to body, 1.25–1.3 mm for lung). Fluid accumulation in each paranasal sinus (maxillary, sphenoidal, ethmoid, frontal) and in the central airways, as well as stomach volume, volume of the stomach contents, and CT number of the (cardiac) atria were examined by segmenting each axial slice (region of interest was set using freehand drawing tools). From the segmented data for each slice, three-dimensionally reconstructed data (3D data) were calculated automatically using a dedicated workstation (SYNAPSE VINCENT). The mean fluid volume and CT number in each area of volume data, as well as standard deviations were calculated. A typical reconstructed 3D data image is shown in Fig. 1 (for the stomach, the figures are of its contents).

Table 2 Causes of death in the control group for investigation of CT numbers of the atria

Control subjects ($n = 24$)	
Cause of death	No. of subjects (%)
Hypothermia	7 (29.2%)
Hanging	6 (25.0%)
Carbon monoxide poisoning	3 (12.5%)
Coronary atherosclerosis	2 (8.3%)
Aortic stenosis	1 (4.2%)
Suffocation (foreign body in the airways)	1 (4.2%)
Suffocation (strangulation)	1 (4.2%)
Hepatic failure	1 (4.2%)
Subdural hematoma	1 (4.2%)
Acute alcohol intoxication	1 (4.2%)

Image interpretation

Diagnoses based on lung images (interpretation of PMCT retrospectively) were established by selecting up to two predominant findings. Two board-certified radiologists reviewed all PMCT data, and discrepancies were resolved via consensus.

Lungs

In accordance with the previous studies [5, 13], we examined abnormalities including areas of ground-glass opacity (GGO) and consolidation. GGOs were defined as opacities in which blood vessels were visible, while consolidation was defined as an opacity in which blood vessels were not visible. GGOs were categorized as Type 1, Type 2, or Type 1 + 2 [5]. Type 1 is defined as a GGO with thickened pulmonary interstitium, Type 2 is defined as a centrilobular distribution of ill-defined nodules along the airways, and mixed type (1 + 2) is defined as a combination of the two [5]. If the diagnosis was difficult to determine (e.g., too many findings in the lungs), the case was diagnosed as “others.”

Fluid accumulation in the paranasal sinuses and central airway

The presence or absence of fluid accumulation in the paranasal sinuses and central airway (from the trachea to the bilateral main bronchi) was evaluated. The volume of fluid and CT numbers in the paranasal sinuses and central airway were calculated using 3D PMCT data. The paranasal sinuses were observed at a window level of 40 HU, and a window width of 120 HU. The central airways were observed at a window level of 50 HU and a window width of 350 HU. The margins of the areas of fluid collection (borderline between fluid and bones or walls) were determined visually. The area of soft tissue density that had air–fluid level was considered to be fluid. An apparent raised surface was judged to be a possible swollen (edematous) wall and was not considered to be an area of fluid. The upper margin of the trachea was considered to be at the level of the lower margin of the cricoid cartilage, and bilateral main bronchi were considered to be the segments that extended from the carina to the bifurcations of the secondary bronchi.

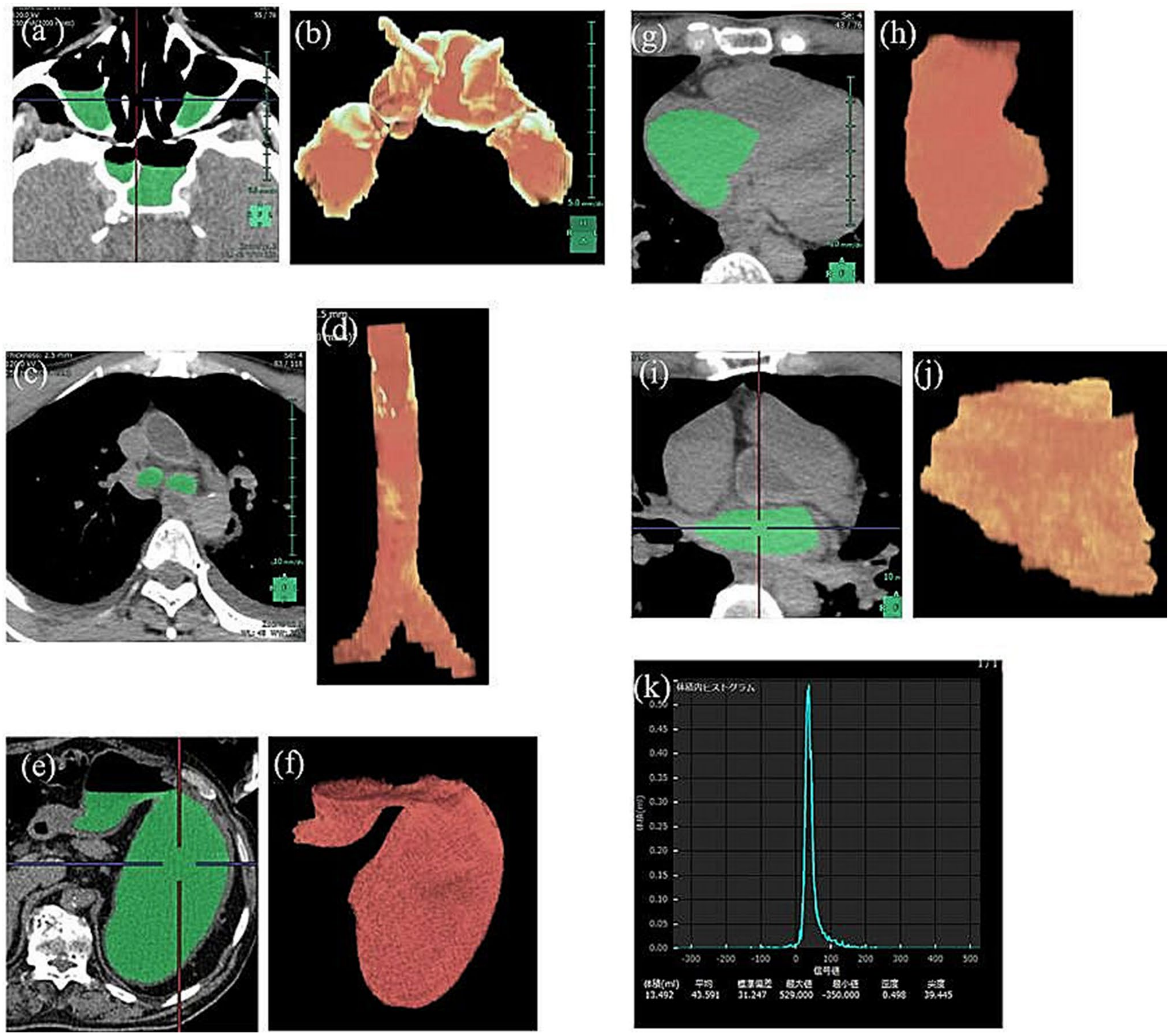

Fig. 1 The methods of generating 3D data. For the paranasal sinuses, the regions of interest (ROIs) (accumulated fluid) were delineated as green-colored areas in each axial image (**a**). The 3D image data were obtained by fusing each slice's ROI using a workstation (**b**). For the central airways, the ROIs (accumulated fluid) were set in the same way as done for the paranasal sinuses (**c**), and 3D images were generated (**d**). For contents of the stomach, the same method was used to obtain images such as (**e**) and (**f**). For the stomach volume, the same method was employed (not shown in the figure). For the right atrium, a similar method was employed to obtain images such as (**g**) and (**h**). For the left atrium, a similar method was used to obtain images such as (**i**) and (**j**). From all of these 3D images, a volume histogram, as well as calculated volume (mL) and mean, standard deviation, and maximum and minimum CT numbers (HU) were obtained, as shown in (**k**)

Stomach

The stomach was assessed using 3D PMCT data. Volume of the stomach and stomach contents, and the mean CT number for the stomach contents were calculated, along with standard deviations where appropriate. The three-dimensional image reconstruction process for the analysis of the stomach (including stomach contents) is presented in Fig. 1. Each area of the axial CT slice was determined by free hand. The margins were delineated visually in the same manner as done in the paranasal sinuses and airways.

CT number for the right and left atria

To evaluate the presence of hemodilution, the CT number was calculated for the right atrium (RA) and left atrium (LA) based on 3D PMCT data. The CT number of the RA and LA, and the difference between the LA and RA (LA minus RA) were calculated in each case. These data were then compared between FWDCs and SWDCs. It was not possible to delineate a perfect border between the lumen and the wall of the atrium. The border of each slice for each chamber was defined as the area 2–3 mm from the margin of the atrium. Each area of fluid in the slice was determined in the same manner as done in the paranasal sinuses, central airway, and stomach. We did not analyze blood density in the ventricles because postmortem changes, such as gas formation, often occur in the ventricles [2]. The confirmatory comparisons of CT number in the atria between FWDCs and controls, as well as between SWDCs and controls were performed because hemodilution occurs only in freshwater drowned subjects.

Other findings

The presence or absence of high-attenuation sediment (suggesting silt-laden freshwater or sand from saltwater) [3] in the paranasal sinuses, airway, and stomach was evaluated. In addition, the presence or absence of fluid collection in the mastoid air cells (temporal bone) and pleural effusion (and its maximal thickness in the axial image, which was calculated as 0 mm in case of no effusion) was evaluated. Some cases of pleural effusion were very small in volume, and in some cases, its margin was unclear. Therefore, we did not acquire a 3D image of it. When examining high-attenuation sediment, to distinguish the object's 'metal' density from blood density, a CT number lower than 100 HU was not considered 'high attenuation'. When examining fluid collection in the mastoid air cells, for cases in which it was difficult to determine whether fluid accumulation had occurred, the case was categorized as "indeterminable."

Statistical analyses

Fisher's exact tests and contingency tables were used to compare the frequency of selected PMCT findings. For continuous quantity, the data were regarded as a normal distribution in the goodness-of-fit test. Therefore, they were compared with unpaired *t* tests (Welch's, unequal variance). All analyses were performed using Statistical Package for the Biosciences (Version 9.6). *P* values less than 0.05 were considered as statistically significant. Values are reported as the mean ± standard deviation.

Results

Lungs

Type 1 lung findings were more frequent in the SWDCs than in the FWDCs ($P = 0.0274$, Table 3). Type 2 and Type 1 + 2 cases showed no apparent difference between the two groups ($P = 0.4447$, $P = 0.6868$, respectively). Typical PMCT images for Type 1 and Type 2 cases are shown in Figs. 2 and 3, respectively.

Fluid accumulation in the paranasal sinuses and central airway

In the paranasal sinuses, the mean volume of fluid was larger in the FWDCs than in the SWDCs ($P = 0.0195$, Table 3). The mean CT number of fluid in the paranasal sinuses was lower in the FWDCs than in the SWDCs ($P = 0.0104$). In all subjects across the two groups, fluid was observed. In the central airway, the frequency of fluid and the mean volume of the fluid showed no apparent difference between the two groups ($P = 1.0000$, $P = 0.2992$, respectively). The mean CT number of the fluid was lower in the FWDCs than in the SWDCs ($P = 0.0077$).

Stomach

The mean volume of the stomach and stomach contents showed no significant difference between the two groups ($P = 0.5499$, $P = 0.5790$, Table 3). The mean CT number of the stomach contents was lower in the FWDCs than in the SWDCs ($P = 0.0216$).

CT number of the right and left atria

The mean CT number of the RA showed no significant difference between the two groups ($P = 0.8692$, Table 3). The mean CT number of the LA was lower in the FWDCs (48.9 ± 9.4 HU) than in the SWDCs (62.0 ± 11.4 HU, $P = 0.0029$). The difference in CT number between the bilateral atria (LA minus RA) was smaller in the FWDCs (4.7 ± 13.1 HU) than in the SWDCs (14.4 ± 10.8 HU, $P = 0.0247$).

In the confirmatory comparison between FWDCs and controls, the mean CT number of the LA was lower in the FWDCs than in the controls ($P = 0.0026$, Table 4); whereas, no apparent differences were observed in the CT number of the RA between these groups ($P = 0.5542$, Table 4). The difference in the CT number of the bilateral atria (LA-RA) was lower in the FWDCs than in the controls ($P = 0.0311$, Table 4). No apparent differences in the CT numbers of the RA and LA ($P = 0.4462$, $P = 0.1857$, respectively; Table 5) or bilateral atria (LA-RA) were observed between the SWDCs and controls ($P = 0.0618$, Table 5).

Other findings

The results of fluid collection in the mastoid air cells (temporal bone) were as follows. In the FWDCs ($n = 25$), the

Table 3 Comparison of CT findings between fresh water and salt water drowning cases (mean ± standard deviation, or number)

	Fresh water drowning ($n=25$)	Salt water drowning ($n=12$)	P value[a]
Lungs			
Type 1	6 (24.0%)	8 (66.7%)	0.0274
Type 2	8	2	0.4447
Type 1 + 2	7	2	0.6868
Others	4	0	1.0000
Fluid in the paranasal sinus			
Fluid accumulation existed (no. of cases, percentage)	25 (100.0%)	12 (100.0%)	(unmeasurable)
Mean volume of fluid (mL)	13.3 ± 7.7	7.3 ± 5.6	0.0195
Mean CT number (HU)	26.7 ± 9.4	35.9 ± 9.2	0.0104
Fluid in the central airway			
Fluid accumulation existed (no. of cases, percentage)	21 (84.0%)	10 (83.3%)	1.0000
Mean volume of fluid (mL)	16.5 ± 10.2 ($n=21$)[b]	20.8 ± 10.5 ($n=10$)[b]	0.2992
Mean CT number (HU)	12.0 ± 7.4 ($n=21$)[b]	21.0 ± 7.8 ($n=10$)[b]	0.0077
Stomach			
Mean volume of the stomach (mL)	581.3 ± 290.7	641.9 ± 280.9	0.5499
Mean volume of stomach contents (mL)	285.5 ± 202.3	324.5 ± 194.4	0.5790
Mean CT number of stomach contents (HU)	8.5 ± 13.3	18.9 ± 11.4	0.0216
Cardiac chambers			
Mean CT number of the right atrium (HU)	48.0 ± 9.5	47.6 ± 6.2	0.8692
Mean CT number of the left atrium (HU)	48.9 ± 9.4	62.0 ± 11.4	0.0029
Mean difference of CT number between the left and right atria (LA-RA, HU)	4.7 ± 13.1	14.4 ± 10.8	0.0247

[a]Welch's *t* test or Fisher's exact test

[b]Fluid in the central airway was not present in four subjects in the FWDCs group and two subjects in the SWDCs group. Consequently, CT number of the fluid could not be determined

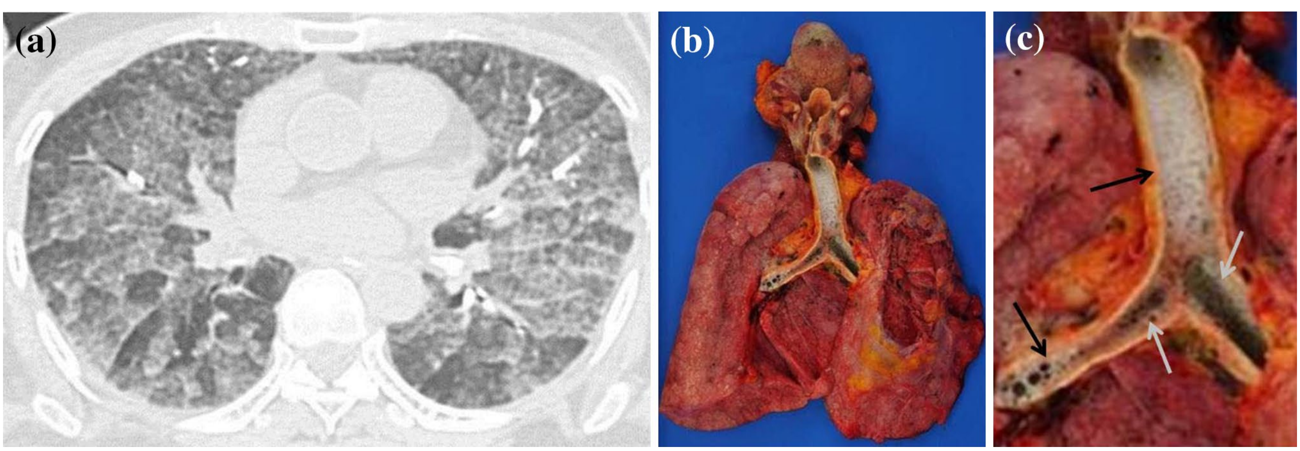

Fig. 2 Ground-glass opacity (GGO) of a Type 1 finding on postmortem computed tomography (PMCT): a salt water (seawater) drowning case of a 68-year-old woman. Type 1 findings appeared as a fine reticular pattern superimposed on areas of GGO and were associated with GGOs and a thickened pulmonary interstitium (**a**). At autopsy, the lungs appeared congested and edematous (**b**). White frothy fluid was observed in the central airways (**c**). **c** The magnified image of a part from (**b**). White frothy fluid (black arrows) and sand (gray arrows) was seen

fluid was present in two subjects (8.0%), and absent in six subjects (24.0%). In the other 17 subjects (68.0%), the fluid presence was indeterminable. In the SWDCs ($n=12$), the fluid was present in four subjects (33.3%), and it was absent in three (25.0%). In the other five subjects (41.7%), the fluid presence was indeterminable ($P=0.3147$).

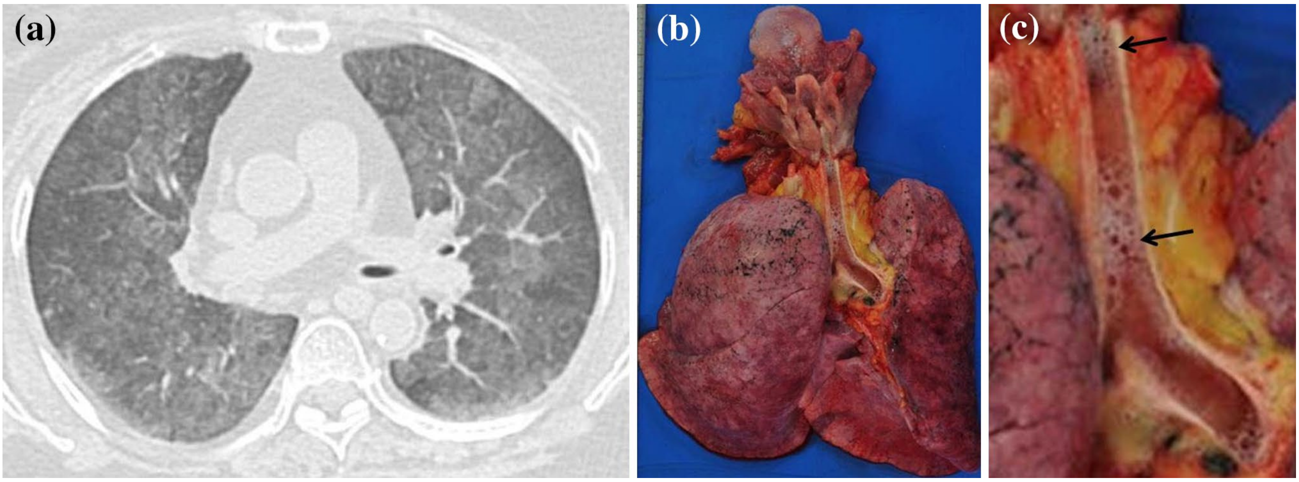

Fig. 3 Ground-glass opacity (GGO) exhibiting a Type 2 feature of the lungs on postmortem computed tomography (PMCT). In this fresh water drowning case, a 67-year-old woman was found floating on the surface of a canal. Postmortem CT revealed GGO with a patchy nodular distribution or a centrilobular distribution of ill-defined nodules along the airways (**a**). At forensic autopsy, the lungs appeared congested and edematous (**b**). Accumulation of frothy fluid was observed in the central airway (**c**). **c** The magnified image of a part from (**b**). White frothy fluid (arrows) was seen

Table 4 Comparison of the CT number of the atria between fresh water drowning cases and controls (mean ± standard deviation, or number)

	Fresh water drowning ($n=25$)	Control ($n=24$)	P value[a]
Mean CT number of the right atrium (HU)	48.0 ± 9.5	49.7 ± 10.0	$P=0.5542$
Mean CT number of the left atrium (HU)	48.9 ± 9.4	56.9 ± 8.0	$P=0.0026$
Difference in mean CT number between the left and right atria (LA-RA, HU)	0.9 ± 10.9	7.2 ± 8.8	$P=0.0311$

[a]Welch's *t* test

Table 5 Comparison of the CT number of the atria between salt water drowning cases and controls (mean ± standard deviation, or number)

	Salt water drowning ($n=12$)	Control ($n=24$)	P value[a]
Mean CT number of the right atrium (HU)	47.6 ± 6.2	49.7 ± 10.0	$P=0.4462$
Mean CT number of the left atrium (HU)	62.0 ± 11.4	56.9 ± 8.0	$P=0.1857$
Difference in mean CT number between the left and right atria (LA-RA, HU)	14.4 ± 10.8	7.2 ± 8.8	$P=0.0618$

[a]Welch's *t* test

The results of pleural effusion were as follows. In the FWDCs, pleural effusion was present in 18 subjects (72.0%), and it was absent in seven (28.0%). The mean maximal thickness of the effusion was 5.16 ± 6.18 mm. In the SWDCs, effusion was present in nine subjects (75.0%) and absent in three (25.0%). The mean maximal thickness of the effusion was 11.17 ± 8.87 mm ($P=0.0527$).

The results of high-attenuation sediment (in the paranasal sinuses, airways, and stomach) were as follows. In the FWDCs, a bulky and apparent high-density area (HDA) was seen in only two subjects (8.0%), and the remaining subjects showed a tiny spotty HDA in the upper or middle pharynges (11 subjects, 44.0%) or in the stomach (one subject, 4.0%). In the SWDCs, one subject (8.3%) showed tiny spotty HDA in the upper or middle pharynges, and the other 11 subjects (91.7%) showed no HDA.

Discussion

In the current study, when examining the heart, we found that the CT number of the LA was significantly lower in FWDCs than in SWDCs. Furthermore, the mean difference in CT number (LA minus RA) was significantly smaller in

FWDCs than in SWDCs. The comparison between FWDCs and controls, as well as between SWDCs and controls confirmed these results. When viewed from a different angle, the CT number in the LA was significantly higher in SWDCs than in FWDCs, and it was higher in SWDCs than in controls—though not significant. In FWDCs, freshwater moves rapidly across the alveolar–capillary membrane into the circulation [14], while in SWDCs, saltwater draws protein-rich liquid from the vascular space into the pulmonary alveoli [14]. These two different movements of water—from lungs to the pulmonary capillaries (as well as LA) and vice versa—resemble two meshed cogwheels rotating opposite direction to each other, which leads us to hypothesize that the hemodilution in FWDCs (as well as its 'inverse' phenomenon) or hemoconcentration in SWDC has been expressed in the PMCT study findings through the LA CT number results. Leth and Madsen [15] reported that it is impossible to separate fresh and salt water drowning cases by comparing the radio densities of the blood in the heart chambers. However, they studied the bilateral ventricles, pulmonary trunk, and ascending aorta, whereas we investigated the atria; this difference can influence the CT number results; this difference might have caused the different results and opinions between them and us. Christe et al. did not analyze blood density in the ventricles because of an expected high-dilution effect in the non-dependent location and gas formation/embolism. There appears to be many different results and opinions surrounding blood densities from varied combinations of cardiac chambers or great vessels. In the future, comparisons of different studies examining the common chambers or vessels might be necessary. It could clarify whether our hypothesis is appropriate.

Regarding the lungs, in the current study, the Type 1 lung feature (opacity) was seen significantly more frequently in SWDCs than in FWDCs. According to Usui et al. (2014), the difference between Type 1 and Type 2 seems to be based on the presence of pulmonary edema and emphysema aquosum (waterlogged and distended lungs of drowning victims [14]). Usui et al. [5] reported that at autopsy, severe edema was observed in 97% of Type 1 cases and that lungs with Type 1 CT findings were usually classified as having severe pulmonary edema [5]. The hypertonic seawater draws protein-rich liquid from the vascular space into the pulmonary alveoli, causing damage to the basement membrane, dilution and washout of surfactant, the reduction of compliance [14, 16], and the rapid occurrence of pulmonary edema [14]. Therefore, Type 1 findings noted in SWDCs could be related to the hypertonicity of the aspirated liquid (seawater), which results in a more severe pulmonary edema than that observed in Type 2 and 1 + 2 cases. In our study, the frequency of Type 2 and 1 + 2 cases was not significantly different between the two groups. Thus, it is likely that the higher frequency of Type 1 cases observed in SWDCs does not strongly contribute to the distinction between SWDCs and FWDCs. However, Type 1 cases seem to represent one of the conditions that occurs in SWDCs, and it can be a positive factor in differentiating between SWDCs and FWDCs. However, we should interpret this result with caution because no significant difference was found between fresh and salt water cases in the experimental comparison [10]; there may be some differences in aspects such as nature of water or mechanism between experimental drowning and actual (human) drowning.

With respect to the paranasal sinuses, the CT number of accumulated fluid was higher in SWDCs than in FWDCs, which is consistent with the previously reported results [9]. In recent studies concerning legal medicine, some materials or ions contained in the water in the paranasal sinuses have been investigated for differential diagnosis in cases of fresh water and seawater drowning [17, 18]. In our study, some material compositions may be attributed to the discrepancy in CT numbers of fluid in the paranasal sinuses between SWDCs and FWDCs. We observed that the volume of accumulated fluid in the paranasal sinuses was significantly larger in FWDCs than in SWDCs, and this result was not similar to that of a previous report [9], which showed no significant difference. In the fresh water drowning cases, the proportions of subjects, based on the scene of drowning, showed a similar tendency in our study and in the previous study [9]. In our study, the major locations were river (40.0%), irrigation ditch, and irrigation channel (28.0%). In the previous study [9], these locations were river (39.4%) and irrigation channel (22.5%). The discrepancy in the results concerning volume of accumulated fluid in the paranasal sinuses between the two studies does not seem to be related to the location of fresh water drowning. In the current study, fluid in all the paranasal sinuses (including the ethmoidal and frontal sinuses) were calculated, while only the maxillary and sphenoidal sinuses were investigated in the previous study [9]. This discrepancy may influence the results mentioned above, although the precise reason for the discrepancy is not clear. We may have to consider the possibility that there might be fluid collection in the paranasal sinus due to sinusitis. Establishing a reliable method that can distinguish drowning-derived fluid from inflammatory fluid accumulation through future research may address this problem.

The mean CT number of accumulated fluid in the central airway and for stomach contents was lower in the FWDCs than in the SWDCs. This result resembles those regarding fluid in the paranasal sinuses. The fluids found in the multiple parts of the body, including paranasal sinuses, central airway, and stomach are presumably derived from the same water from the location where the drowning occurred; therefore, this resemblance is thought to be appropriate. Discrepancies in CT number between the two groups in the paranasal sinuses, central airway, and stomach contents could be a supportive factor in distinguishing FWDCs and SWDCs.

In the present study, the findings from the paranasal sinuses, central airway, stomach, and heart were obtained from image data that had been three-dimensionally reconstructed using a dedicated workstation. Although this method is time-consuming, it is necessary to pursue the accuracy of the data. For example, in previous studies, the volume of the stomach was calculated based on its length, width, and height [2, 4]. However, in our experience, the precise calculation of stomach volume based on these three parameters is difficult, as even a small deviation in any one of these values will alter the calculated volumes. Calculations using three-dimensional image data are thought to minimize this error and can be applied to obtain the volume of other organs as well. This method is thought to be optimal when only non-contrast CT is available.

Concerning findings in the mastoid air cells (of the temporal bone), it was difficult to assess the presence or absence of the fluid there because the resolution of the available CT images (2.5 mm thickness) was too low to observe the cells in detail. This finding may be difficult to apply when diagnosing drowning. Second, with regard to the pleural effusion, the amount seemed to be larger in SWDCs (from its maximal thickness), possibly due to the hypertonicity of sea water. The frequency of the presence or absence of effusion seemed to be similar in the two groups. Thus, it may be difficult to use the frequency of pleural effusion to distinguish FWDCs and SWDCs. Third, with regard to high-attenuation sediment (in the paranasal sinuses, central airway, and stomach), a bulky and apparent pharyngeal high-density area was seen in only two subjects (8.0%) in FWDCs, suggesting mud, and the majority of the remaining subjects showed only a tiny spotty high-density area in the pharynges or stomach. Levy et al. [3] described that 50% of their 28 drowned subjects showed high-attenuation sediment in the subglottic airways. According to their description, 23 of the 28 (82.1%) subjects drowned while submerged in motor vehicles that accidentally overturned into inland canals. The frequency of the high-attenuation sediment is markedly higher than that found in our study. However, the circumstances under which drowning occurred in their study may account for this discrepancy; the majority of their victims died in the interior of a car that was overturned and submerged into an inland canal, which may not contain small amounts of particles, such as mud or sand. The subjects in the current study did not share this unique situation. Therefore, it is difficult to compare the results of these two studies. Given our results, the high-attenuation sediment (especially in the airways) will likely not to be useful in diagnosing drowning or differentiating between FWDCs and SWDCs.

As a limitation, the population was small in this study. However, this situation was unavoidable due to the strict application of exclusion criteria. However, these strict criteria are thought to avoid possible inappropriate PMCT findings for precise diagnosis. For example, our criteria excluded cases in which CPR was administered, which allowed us to avoid possible artifacts in PMCT findings due to CPR, especially in the airways and lungs. In conclusion, among the PMCT findings, a lower density of the left atrium in fresh water drowning cases was observed. Whether this result suggests hemodilution (and relates to hemoconcentration) is unclear, and further research should be performed. The higher frequency of Type 1 lung features (in salt water drowning cases), as well as lower density of accumulated fluid in the paranasal sinuses, central airway, and contents of the stomach (in fresh water drowning cases) may provide a useful clue for diagnosing fresh and salt water drowning.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethical statement The present study was approved by the appropriate institutional review board, who waived the requirement for informed consent due to the nature of the study.

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