Legal Medicine 19 (2016) 11–15

Contents lists available at ScienceDirect

Legal Medicine

journal homepage: www.elsevier.com/locate/legalmed

Short Communication

Experimental drowning lung images on postmortem CT – Difference between sea water and fresh water

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ARTICLE INFO

Article history:
Received 13 October 2015
Received in revised form 28 December 2015
Accepted 12 January 2016
Available online 14 January 2016

Keywords:
Postmortem CT
Experimental drowning
Hypostasis
Postmortem change
Forensic radiology

ABSTRACT

Purpose: Experimental drowning models were prepared to investigate the time-related course of lung changes using postmortem CT. This study was approved by our institutional animal ethics committee.
Materials and methods: Fifteen NZW rabbits (female fifteen, 2.6–4.3 (mean 3.3) kg) were divided into 3 groups: fresh water drowning (FRESH), sea water drowning (SEA), and sea water drowning with anterior chest compression (ACC). All individuals were examined by CT (Aquilion CX, Toshiba, Japan) on postmortem time course. The rabbit's head was submerged in a water bath for a total of 10 min. In ACC, cardiopulmonary resuscitation was performed for 2 min, additionally. The percentage of aerated lung volumes (%ALV = 100 (aerated lung volume/total lung volume)) were statistically evaluated and the lung CT image patterns and pleural fluid appearance time were investigated.
Results: All lungs had decreased their %ALV within 24 h, and there were no statistical differences in and among the 3 groups. After 36 h, %ALV tended to increase in all groups, and only ACC presented a statistical difference between 1 h and 36 h ($p < 0.005$).

On postmortem lung CT, all lungs presented ground-glass opacity with interstitial thickening spread pattern (100%) and no pattern change during the follow-up period. After presenting pleural space fluid collection, the %ALV tended to increase.
Conclusion: There were no differences among FRESH, SEA, and ACC in %ALV within 24 h. Only ground-glass opacity could be detected on postmortem lung CT, experimentally.

1. Introduction

Drowning is one of the most frequent causes of accidental death in Japan [1] and the third leading cause of accidental death in the Unites States [2]. The diatom test is still considered as the gold standard in diagnosis of drowning [3]. In addition, the pleural space fluid osmotic evaluation has been used to evaluate drowning cadavers [4–6]. Pette et al. reported that the combination of diatom test with autopsy findings is important in making a conclusion about cause of death [3].

In recent years in forensic radiology, many imaging experiences have been reported, and in the cases involving drowning, third space fluid (such as in the paranasal sinuses, mastoid air cells, trachea/tracheal bronchus) has been reported as a supportive finding of drowning [7–9]. The appearance inside the lung in drowning has been also reported, and the postmortem computed tomography (CT) images of drowning cases can be classified into three major types [10]. In contrast, many of the findings in drowning were also present in non-drowning asphyxiation, and the findings were not specific to only a single cause of death [11].

In our previous study, we determined the lung findings on postmortem CT, and it had differently presented in individual causes of death depending on the postmortem interval [12]. It is thought that sea water and fresh water drowning affect the postmortem lung CT findings differently. But in our literature review, there is no report evaluating the distinction between sea water and fresh water drowning in the assessment of lung findings on postmortem CT. Therefore, in this study, we experimentally investigate and evaluate the differences in lung appearance between sea water and fresh water drowning.

2. Materials and methods

This study was approved by our institutional animal ethics committee (2013/10/11, 13-074). From November 2013 to March

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http://dx.doi.org/10.1016/j.legalmed.2016.01.006
1344-6223/

2015, adolescent female New Zealand White rabbits ($n = 15$, weighing 2.6–4.3 (average 3.3) kg) were enrolled in this study. According to the causes of death procedure, they were divided into three groups ($n = 5$ each): fresh water drowning (FRESH), sea water drowning (SEA), and sea water drowning with anterior chest compression (ACC). After deep sedation procedure (Xylazine intramuscular (i.m.) 4 mg/kg, Ketamine i.m. 50 mg/kg), they were all examined by CT as a pre-procedural image.

For the FRESH and SEA group, the rabbit's head was submerged in a tap water and sea water (collected from the harbor) bath, and kept in position for 10 min. For the ACC group, the rabbit's head was submerged in sea water for a total of 10 min. The rabbit was taken out from the water bath and anterior chest wall manual compression was carried out for 1 min at 1 and 3 min after postmortem period to evaluate the effect of cardiac massage change on the lung CT image. At the confirmation of termination of anterior chest wall heartbeat, respiratory function, and dilatation of pupils, the time of death was estimated for all bodies.

2.1. CT examination

After taking the pre-procedural CT image, all the rabbits were sacrificed by drowning. Then, the bodies were put into a sealed body bag and placed in the CT room (20 degrees Celsius) through the whole observation period. According to the time schedule (postmortem time: 1, 2, 3, 4, 5, 6, 12, 24, and 36 h), the whole bodies were examined by CT with minimum body re-positioning.

A 64-slice multi-detector CT scanner (Aquilion CX, Toshiba, Tochigi, Japan) was used, employing the following protocol: 120 kV, 200 mA, 0.5 s/rotation, pitch factor 0.641, configuration 0.5×32, reconstruction 0.5 mm.

All of the datasets were stored in the DICOM format. The DICOM data were transferred to a workstation (SYNAPSE VINCENT V4.1, FUJIFILM, Tokyo, Japan). Using manual adjustments, total lung volume and aerated lung volume (ALV) (-700 to -1000 HU) were measured semi-automatically and the results were confirmed by a board-certified radiologist.

2.2. Imaging analysis

2.2.1. Pulmonary aeration

Using the following formula, the percentage of aerated lung volume (%ALV) was calculated:

$$\%\text{ALV} = (\text{ALV}/\text{total lung volume}) * 100$$

2.2.2. Assessment of lung images

One board-certified radiologist and one board-certified forensic pathologist assessed the CT images (axial 0.5 mm and 7.0 mm reconstruction). The postmortem lung CT was evaluated according to the CT appearance (diffuse ground-glass opacity (GGO), interstitial linear density, and/or centrilobular consolidation) and its distribution dependency (dorsal, ventral, or diffuse). Using axial source images, the appearance time of pleural space fluid collection was documented. Both experts carried out independent assessments in order to mutually confirm their findings.

2.3. Statistical analysis

To evaluate the statistical difference, the %ALV was compared according to the time difference in each group (intra-group comparison), and compared among the groups (inter-group comparison). The pleural space appearance times were compared among the 3 groups. The StatView (SAS Institute Inc., North Carolina, USA, version 5.0) software was used with a Bonferroni/Dunn study. Differences with $p < 0.05$ were considered statistically significant.

3. Results

At the ante-mortem stage, there were no statistical differences among the 3 groups (Table 1). The ante-mortem lung CT images presented without abnormal lesion such as emphysematous change and/or increasing interstitial change. The procedure of sacrificing by drowning completed in all bodies without difficulty. In the ACC group, because of the resuscitation procedure, the submerged body was removed from the water bath, and water containing small bubbles emerged from the rabbit's mouth. The whole body PMCT was performed on all bodies without difficulty.

3.1. Pulmonary aeration (%ALV) (Fig. 1)

In intra-group comparison, decreased %ALV was detected from 1-h to 24-h postmortem period, and there were statistical differences compared with ante-mortem lung images in FRESH and SEA. In ACC, %ALV decreased compared with ante-mortem lung image from 1-h to 24-h postmortem period, but no statistically significant difference presented.

In inter-group comparison, ACC tended to increase the %ALV compared with FRESH and SEA, but the differences were not statistically significant.

3.2. Assessment of lung images (Fig. 2)

In all groups, the postmortem lung CT images presented a ground-glass opacity pattern with interstitial linear density in all 15 rabbits. This presentation was distributed diffusely and uniformly in both lungs. During the observation period, the ground-glass opacity pattern was presented and did not change in all groups. There was no centrilobular consolidation in this study.

Pleural space fluid first appeared at 5–24 (mean 13.4) h in FRESH, 12–24 (16.8) h in SEA, and 12–36 (24.0) h in ACC on PMCT, but the appearance time difference was not statistically significant between any of the 3 groups.

4. Discussion

One of the recent topics which has been gaining attention in forensic radiology is postmortem CT, and drowning lung appearance is one of the main topics in postmortem CT. The lung appearance on postmortem CT has been reported in human cadaver, and it is changed depending on postmortem time [12,13], the difference in individual causes of death [12,14], and the additional resuscitation procedure [15].

Drowning lung CT appearance had been reported in several patterns, such as air space consolidation and/or mosaic pattern [8] and air-space consolidation and centrilobular nodules [16]. Usui et al. reported the 3 major types in drowning PMCT findings (ground-glass opacities with thickened pulmonary interstitium, a centrilobular distribution of ill-defined nodules along the airways, and a combination of these) and the effect of the existence of emphysema and/or fibrosis has been reported [10]. In this study, only ground-glass opacity with interstitial linear density presented on postmortem CT, and there were no significant differences among FRESH, SEA and ACC groups. We speculated that because a uniform procedure had been used to bring about drowning, without a near-drowning situation and/or lung emphysema or interstitial change, our experiments resulted in only ground-glass opacity in postmortem lung CT. There is no doubt that drowning lung CT has several patterns, but we can assess that the ground-glass opacity is one of the typical appearances obtained. If other drowning processes had been used (e.g. using near-drowning period) instead of our procedure, other postmortem lung CT presentations might