Time-related course of pleural space fluid collection and pulmonary aeration on postmortem computed tomography (PMCT)

Hideki Hyodoh *, Jyunya Shimizu, Satoshi Watanabe, Shunichiro Okazaki, Keisuke Mizuo, Hiromasa Inoue

Department of Legal Medicine, Sapporo Medical University, S1 W17 Chuo-ku, Sapporo 060-8556, Japan

A R T I C L E   I N F O
Article history:
Received 25 September 2014
Revised in revised form 7 January 2015
Accepted 7 January 2015
Available online 21 January 2015

Keywords:
Postmortem CT
Hypostasis
Pleural effusion
Postmortem change
Forensic radiology

A B S T R A C T
Postmortem CT (PMCT) is increasingly used in forensic practice, and knowledge and classification of typical postmortem imaging findings would facilitate the interpretation of PMCT. The goal of this study was to define the time-related course of postmortem chest findings. Twelve cadavers (eight male, four female, 27–81 [mean, 60.0] years) were examined twice by PMCT within an interval of time (4–164 h [mean, 30.8; median, 17.5]). The pleural-space-fluid volume, pulmonary parenchyma volume, decreased aerated lung volume (DLV), %DLV (=DLV/pulmonary parenchyma volume) and chest cavity volume were compared between the first and second PMCT examinations. To evaluate the volume change rate, the rate of increase in pleural space fluid volume (mL/h) and the DLV rate (mL/h) were plotted according to the postmortem period. On the second PMCT, the volume of pleural space fluid (p = 0.0469) and %DLV (p = 0.0161) were significantly increased. The increase rate of the pleural space fluid increased at approximately 30 h and the volume continued to increase until approximately 40 h after death. The rate of DLV constantly decreased in the early postmortem period. In conclusion, the pleural-space-fluid collection and the DLV increased over different time-related courses in the postmortem period.

1. Introduction

A recent topic of interest in forensic radiology is post-mortem imaging using computed tomography (CT) [1–5]. Because postmortem biological conditions are different from antemortem conditions, antemortem and postmortem CT findings differ, leading to potential difficulties in distinguishing normal postmortem changes from those associated with the individual’s pathology [1,3–15].

The knowledge and classification of typical postmortem imaging findings would facilitate the interpretation of specific postmortem imaging findings. For example, in forensic pathology, lung volume, weight, air content, and pleural space fluid are important indicators for investigating the cause of death, and quantitative analysis of pulmonary air content may provide additional information with relevance to pathology at autopsy [16,17]. On the other hand, a postmortem increase of pleural space fluid collection during early postmortem period and the decrease thereafter, accompanied by reduced lung weight is known in cases of wet lung [18,19]. The time-related course of pleural space fluid and pulmonary aeration has been expected [9], but no article has described the quantitative evaluation of time-related pulmonary changes on postmortem CT (PMCT). The purpose of our study was to investigate postmortem imaging findings using objective data and to define the time-related course of postmortem changes on chest CT.

2. Materials and methods

This study was approved by our institutional ethics committee. Between April 2013 and October 2013, 199 non-criminal cadavers were transported to our department for inspection. After a PMCT, external examination, tracheal endoscopy, and examination of biochemistry/toxicology, a full autopsy was suggested by a forensic pathologist. With the court’s permission, 12 bodies (8 male and 4 female, 27–81 [mean, 60.0] years old) were examined by a full autopsy. Before the autopsy, a PMCT was repeated (time interval 4–164 h [mean, 31.9]). The postmortem periods were 18–420 h (mean, 81.8) (Table 1). The causes of death, confirmed by the full autopsy, were as follows: drowning (sea water n = 2, fresh water n = 1) (Fig. 1), subdural hemorrhage (n = 2), peritoneal hemorrhage (n = 1), cardiac rupture (n = 1), carbon monoxide intoxication (n = 1), hypoglycemia (n = 1), myocardial infarction (n = 1), suffocation (n = 1) (Fig. 2), and unknown (n = 1). The evaluation excluded cardiopulmonary resuscitated cases, children (defined as individuals aged <20 years old), and those with major chest trauma.

* Corresponding author. Tel.: +81 11 611 2111x2752; fax: +81 11 611 3935.
E-mail address: hyodoh@sapmed.ac.jp (H. Hyodoh).
2.1. Imaging protocol

All of the bodies were imaged in sealed body bags in the supine position with the arms adjacent to the body using a 64-detector CT scanner (Aquilion CX, Toshiba, Tochigi, Japan) using the following protocol. First session: neck to head; 120 kV, 300 mA, 1.0 s/rotation, pitch factor 0.641, configuration 0.5 x 32, reconstruction 0.5 mm, MPR (multi-planar reformation) image reconstruction: 5 mm in the axial, sagittal, and coronal sections. Second session: neck to foot; 120 kV, 50–400 mA (variable mA), 0.5 s/rotation, pitch factor 0.828, configuration 0.5 x 32, reconstruction 0.5 mm, MPR image reconstruction: 7 mm in the axial plane and 5 mm in the sagittal and coronal planes.

After the first PMCT examinations, the bodies were stored in a refrigerator, and after an interval of time, the bodies were transferred to our institute to undergo the same protocol on second PMCT prior to an autopsy. A full autopsy was then performed by a board-certified forensic pathologist.

2.2. Imaging analysis

All of the datasets were stored in the DICOM format. The DICOM data were transferred to a workstation (SYNAPSE VINCENT V3.3.0003, FUJIFILM, Tokyo, Japan). Using an automatic lung analyzer with manual adjustments, we measured the following volumes: pleural space fluid volume, pulmonary parenchyma volume, decreased aerated lung volume (DLV, CT value: 699 HU), percent DLV (%DLV = DLV/pulmonary parenchyma volume), and chest cavity volume. The VINCENT software has an automatic measurement tool, and we used the thresholds from 0 to –699 HU for the DLV, as previously reported [2]. These analyses were performed by one radiologist with re-evaluation by one forensic pathologist.

2.3. Statistical analysis

To evaluate the accuracy of virtual measurement, the virtual pleural space fluid volume was compared with measured pleural space fluid volume at autopsy. Using the reported formula (lung weight (g) = lung volume (ml) x [1 + mean CT attenuation value per voxel (HU)/1000]) [16,20], the lung weight was also compared with measured lung weight. To evaluate the correlation between the “dry-and wet-lung” (1000 g as a cutoff point [21]), all parameters were statistically evaluated with the lung weight. The first and second PMCT groups were compared according to the pleural space fluid, DLV, pulmonary volume, and chest cavity. We used JMP (SAS Institute Inc., North Carolina, USA, version 11.0.0) software with a Mann–Whitney U-test for the comparisons between the first and second PMCT examinations, and Mann–Whitney U-test/Pearson’s correlation test for the lung weight and virtual measurements. Differences of p < 0.05 were considered statistically significant.

To evaluate the volume change per hour in the pleural fluid and DLV, we plotted the increasing volume rate (mL/h) on the y-axis and the post-mortem period on the x-axis.

3. Results

3.1. Volumetry (Table 1)

3.1.1. Virtual measurements

The volume of pleural space fluid in the first PMCT, second PMCT and the autopsy were 110.0 ± 72.1 mL, 160.0 ± 89.0 mL,
and 162 ± 79.4 mL, respectively. Compared with the autopsy group, there was a statistically significant difference in the first PMCT ($p = 0.0425$), but no significant difference in the second PMCT ($p = 0.074$).

The weight of lung in the first PMCT, second PMCT and the autopsy were 701.2 ± 164.2 g, 691.5 ± 146.8 g, and 1040.9 ± 109.4 g, respectively. Compared with the autopsy group, there were significant correlations in the first ($p < 0.0001$) and the second ($p = 0.00003$), PMCT. The DLV ($p = 0.0104$) and pulmonary parenchymal volume ($p = 0.0104$) showed statistically significant difference between “dry-and wet-lung” and the $R^2$ were 0.676 and 0.676, respectively.

### 3.1.2. Pleural space fluid volume

Comparing the first and the second PMCT, there was a statistically significant difference between the groups ($p = 0.0469$) and the pleural space fluid increased at the second PMCT (Fig. 3a). The shortest post-mortem period was 18 h in our series; thus, data prior to 18 h were not available.
3.1.3. Pulmonary parenchyma volume

The pulmonary parenchyma volume was 1324.5 ± 184.0 mL on the first PMCT and 1344.0 ± 158.0 mL on the second PMCT. There was no statistically significant difference between the first and second PMCT examinations ($p = 0.4238$).

3.1.4. DLV and %DLV (=DLV/pulmonary parenchyma volume)

The DLV and %DLV were 1324.5 ± 184.0 mL, 57.1 ± 6.9% on the first PMCT and 1373.8 ± 144.4 mL, 62.3 ± 6.5% on the second PMCT, respectively. There was significant difference between the two groups in %DLV ($p = 0.0161$) (Fig. 3b) and the lung aeration was significantly decreased on the second PMCT.

3.1.5. Chest cavity volume

The volume of chest cavity was 2239.2 ± 255.9 mL on the first PMCT and 2240.0 ± 185.6 mL on the second PMCT. There was no statistically significant difference between the first and second PMCT examinations ($p = 0.154$).

3.2. Increasing rate

3.2.1. Increasing rate of pleural space fluid

From 18 h to 30 h, the increasing rate of pleural space fluid was zero (mL/h), but its rate increased and peaked at 30 h (Fig. 4a). Its rate of increasing decreased over the next 12 h, and at 42 h after death, the rate was nearly equal to zero (Fig. 4b).

3.2.2. Increasing rate of DLV

The time-dependent DLV rate plot showed a decrease within the first 30 h and then became nearly equal to zero (Fig. 5a and b).

4. Discussion

Pleural space fluid collection is a common postmortem finding [22], and it is thought of as postmortem transudation from the lungs [19]. Yajima et al [23] reported that the pleural fluid volume is likely to increase with postmortem time in drowning cases. But there was no data where the pleural space fluid starts/stops increasing into postmortem period. According to our results, the alveolar space fluid dose not effuse into the pleural cavity noticeably within 30 h, the increase rate of pleural space fluid detected rises from 30 h to 42 h, and decreases after 42 h postmortem period. This is the first report where the pleural space fluid starts to increase and subsequently ceases to increase.

Understanding time-related phenomenon of pleural fluid collection, we can interpret that pleural fluid collection was not a standard postmortem change in the first 30 h except as a preexisting antemortem condition. In other words, PMCT can demonstrate the antemortem pleural space condition within 30 h. In addition, the pleural space fluid collection increased from 30 h to 42 h, and it reached maximum volume after 42 h in the postmortem period. Therefore, if the alveolar space fluid is needed to evaluate the electrolyte analysis (e.g. differentiate between freshwater and seawater drowning) [23,24], the examiner should consider the postmortem time to examine and to decide the result.

Zhu et al [19] reported that the total value of the combined lung weight and the amount of pleural effusion may possibly be due to a leakage of the effusion out of the thoracic cavity in seawater.
immersion and it may more greatly reduce the total lung weight. However, findings on the lung weight difference between freshwater and seawater drowning are controversial. In our subjects, the drownings were 2 in seawater and 1 in freshwater, and it is difficult to evaluate the lung weight after time related change.

As a result of natural postmortem changes, the lungs showed advanced dependent opacity and consolidation corresponding to congestive pulmonary edema [9]. This phenomenon is well-known as a postmortem time-dependent change in hypostasis and shows differences in the fluid content, congestion, and edema [25–29], which is more marked posteriorly [28]. Michiue et al. [30] reported that the characteristic pulmonary air distribution regarding the causes of death and the pulmonary opacity is dependent on the severity and duration of heart failure, circulatory blood volume, pulmonary air distribution, and pulmonary congestion during the agony period. According to our results, the postmortem time affects the pulmonary air distribution and the DLV increased more rapidly over a shorter period. Therefore, if the cadaver is examined in the late postmortem period, normal postmortem changes might overlap with some causes of death. An immediate PMCT may be more suitable for evaluating pulmonary pathology than a delayed PMCT.

The pulmonary volume significantly decreased in the second PMCT examination. The mean time difference between the two PMCT examinations was approximately 30 h, therefore the pleural space fluid compressed the lung parenchyma. Decreasing lung volume tended to lead to DLV increasing. We speculated that hypostasis, malacia, colligation, putrefaction, and autoysis might also affect the decrease in pulmonary volume. It was difficult to evaluate these phenomena using only imaging factors.

The first limitation of our study was that the total number of examinations was limited. The collection of more early postmortem period cadavers might allow the detection of time-related changes in more detail. Second, the causes of death were limited, and we did not evaluate cause-related post-mortem pulmonary changes. Specifically, we did not evaluate cardiopulmonary resuscitation cases. Third, we used the postmortem period from the evaluation of the autopsy findings, and the error range might be a few hours.

In conclusion, we retrospectively evaluated the PMCT imaging findings of autopsied cases and showed that the pleural space fluid collection and DLV changed in early postmortem period and ceased in late postmortem period. An understanding of the pleural space fluid collection and DLV change along with postmortem time can help avoid misinterpretations, and understanding of these meanings is important for a correct radiological interpretation.

Acknowledgements

This study was supported by JSPS KAKENHI Grant-in-Aid for Scientific Research (C), Japan (Grant No. 25461836).

We thank Prof. Dr. Myles O’Brien (Mie Prefectural College of Nursing, Tsu, Mie, Japan) for assistance with English language.

References