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Postmortem virtual volumetry of the heart and lung *in situ* using CT data for investigating terminal cardiopulmonary pathophysiology in forensic autopsy

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ABSTRACT

Postmortem CT (PM–CT) is useful to investigate the viscera *in situ* before opening the body cavity at autopsy. The present study investigated heart and lung volumes *in situ* with regard to the cause of death as possible indexes of terminal cardiopulmonary dysfunction by means of PM–CT data analysis of forensic autopsy cases within 3 days postmortem ($n = 70$). Estimated heart volume was larger in sudden cardiac death (SCD; $n = 10$) and fatal methamphetamine abuse ($n = 5$) than in other groups, including mechanical asphyxiation ($n = 12$), drowning ($n = 11$), acute alcohol/sedative–hypnotic intoxication ($n = 8$), fire fatality ($n = 12$), hyperthermia (heatstroke; $n = 6$) and fatal hypothermia (cold exposure; $n = 6$). Estimated combined lung volume was larger in drowning, smaller in fire fatality due to carbon monoxide intoxication and SCD, and intermediate in other groups. Volume ratio of the lung to heart was higher in drowning, lower in SCD, and intermediate or varied in other groups; high and low ratios can indicate predominant/antecedent pulmonary and cardiac dysfunctions, respectively. These findings provide quantitative data that are not available at conventional autopsy or by routine two-dimensional CT morphology to assess three-dimensional gross heart and lung morphologies for interpreting terminal cardiopulmonary pathophysiology, detecting significant difference between SCD and other causes of death, especially mechanical asphyxiation and drowning.

1. Introduction

In forensic autopsy, heart and lung weights as well as the volumes are anatomical indications of central congestion and pulmonary congestion or aeration [1,2]. Cardiac death cases have enlarged heavy hearts and heavy lungs, while the heart is smaller in asphyxiation and drowning, but the lungs are overinflated and heavy in drowning, and inflated with air in asphyxiation [3]. However, heart and lung volumes are substantially modified after opening the thoracic cavity, due to the diminished volume of air-rich lung and possible blood redistribution in the heart and great vessels; thus, it is not possible to measure or evaluate correct heart and lung volumes by dissection. Recent advances in forensic radiology include postmortem imaging using computed tomography (CT) and magnetic resonance imaging (MRI), which provides a non-invasive procedure to detect bone and visceral lesions (virtual autopsy) as well as various possibilities to analyze the status of viscera before autopsy [4–9]. Postmortem CT (PM-CT) is useful to investigate the viscera *in situ* before opening the body cavity at autopsy, especially for the thoracic viscera, presenting quantitative data to supplement autopsy findings [10–16]. Previous studies demonstrated the application of PM-CT data analysis to investigate the lung volume and air/gas content [17]. Virtual volumetry of the viscera *in situ* is an advantage of PM-CT, providing quantitative data that are not available at conventional autopsy; however, there are no published data on *in situ* analysis of the heart and lung volumes using PM-CT data.

The present study investigated the procedure to estimate postmortem volumes of the heart and lung *in situ* as possible indexes of

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terminal cardiopulmonary pathophysiology, using PM-CT data of forensic autopsy cases without evident decomposition, or destruction or deformity of the chest, and analyzed the data with regard to the cause of death.

2. Materials and methods

2.1. Materials

Forensic autopsy cases ($n = 70$) within 3 days postmortem, in which the causes of death had been clearly established, were used in the present study, excluding cases having significant ante- or postmortem body destruction or decomposition, involving destruction or deformity of the chest due to injury, burns or surgical intervention, hemo-/pneumothorax, massive pleural effusions, and putrefactive changes with gas formation. The cases comprised those of mechanical asphyxiation ($n = 12$), drowning ($n = 11$), drug intoxication ($n = 13$), including fatal methamphetamine (MA) abuse ($n = 5$) and alcohol/sedative–hypnotic intoxication ($n = 8$), fire fatalities ($n = 12$) due to burns with blood carboxyhemoglobin level (COHb) of < 30% ($n = 6$) and carbon monoxide (CO) intoxication with blood COHb of > 60% ($n = 6$), hyperthermia (heatstroke; $n = 6$), fatal hypothermia (cold exposure; $n = 6$), and sudden cardiac death (SCD; $n = 10$). Details are shown in Table 1. Cases with significant complications of disease or trauma involved in other cause of death groups, or prolonged deaths in hospital after temporary recovery by cardiopulmonary resuscitation or under critical terminal care, were excluded. Pathological and radiographic data, including heart and lung weights, and recovered heart blood volume as well as the cardio-thoracic ratio on chest radiograph, were collected from autopsy documents.

2.2. CT data analysis

Whole body PM-CT scans were routinely performed immediately before forensic autopsy, employing a scanner (ECLOS, Hitachi Medical Co., Tokyo) within the framework of routine casework. The sequential scanning was performed under the following parameters: 120 kV; 250 mA; 16×1.25 mm thickness; field of view, 500 mm. A CT data analysis system Volume Analyzer SYNAPSE VINCENT (FUJIFILM Medical Co., Ltd., Tokyo) was used to reconstruct three-dimensional (3-D) images of the heart and lungs *in situ* for virtual volumetry, as follows: bilateral lungs were extracted automatically using clinical normal lung threshold ($-2000 < HU < -190$), followed by manual cursoring to fill the high attenuation and consolidation areas inside the thorax, while the heart was extracted by manual cursoring from the ascending aorta up to 3 cm above the aortic valves to the bottom of the heart (Fig. 1). These analyses were performed by forensic pathologists and two radiological technicians in consultation with radiological specialists. The adequacy of virtual analysis was examined by two independent observers as well as by comparing the weights estimated using CT attenuation (Hounsfield Unit, HU). The data analyses were approved by our institutional ethics committee as part of our research project.

2.3. Statistical analyses

Regression equation analysis was used to examine the relationship between pairs of parameters, including age, postmortem interval and survival period. Fisher's exact test was used to compare two parameters. Steel–Dwass test was used for non-parametric multiple comparisons among groups. Comparisons between two groups were performed using the nonparametric Mann–Whitney's *U*-test. The sensitivity and specificity in distinguishing

Table 1
Case profiles.

Cause of death	N	Male/female	Age (years) (median)	Survival time (h)	Postmortem time (h) (median)	Heart weight (g) (median)	Lung weight (g) (median)	Total heart blood volume (ml) (median)	CTR (%) (median)
Mechanical asphyxiation	12	6/6	26–87 (71)	<0.5	12–65 (27.5)	265–515 (368)	695–1800 (1017.5)	50–350 (90)	43.7–65.6 (57.0)
Drowning	11	6/5	19–79 (64)	<0.5	6–62 32.5)	260–605 (320)	595–1565 (1215)	50–250 (125)	40.0–62.9 (54.1)
Fire fatalities	12								
Burns[a]	6	4/2	61–84 (69)	<0.5	12–32 (25.0)	225–630 (295)	515–1150 (727.5)	120–450 (200)	45.6–66.9 (55.5)
CO intoxication[b]	6	4/2	42–77 (68)	<0.5	8–38 (27.0)	280–500 (388)	790–1210 (1072.5)	50–220 (150)	51.4–68.2 (60.3)
Alcohol/sedative–hypnotic intoxication	8	2/6	26–43 (36)	6–12	26–62 (38.0)	210–420 (265)	845–1570 (1065)	50–200 (100)	50.6–58.4 (56.4)
Methamphetamine abuse	5	4/1	45–50 (47)	<6	28–62 (31.0)	340–510 (375)	795–1865 (1075)	120–450 (250)	42.2–66.7 (54.6)
Hyperthermia (heatstroke)	6	4/2	60–83 (74)	6–12	20–61 (30.0)	305–510 (400)	585–1480 (1102.5)	60–300 (100)	46.2–64.6 (58.1)
Hypothermia (cold exposure)	6	3/3	50–91 (79)	6–12	22–62 (31.0)	230–400 (330)	375–960 (655)	50–500 (115)	46.2–66.7 (58.5)
Sudden cardiac death	10	8/2	44–81 (62)	<0.5	14–34 (20.5)	235–540 (423)	535–1765 (1227.5)	60–550 (220)	47.2–70.3 (59.8)
Total	70	41/29	19–91 (62)	–	6–65 (30.0)	210–630 (355)	375–1865 (1025)	50–550 (150)	40.0–70.3 (57.0)

Blood carboxyhemoglobin level (COHb) of (a) <30% and (b) >60%; CO, carbon monoxide; CTR, cardio-thoracic ratio.