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Analysis of postmortem changes in internal organs and gases using computed tomography data

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Abbreviations:
body mass index (BMI)
body surface area (BSA)
computed tomography (CT)
postmortem computed tomography (PMCT)
postmortem interval (PMI)
variance inflation factor (VIF)

Highlights

- We investigated postmortem changes using CT data.
- We analyzed relationships between PMI and lung volume, intrahepatic gas, and intrarectal gas.
- Intrarectal gas decreased with postmortem changes, while intrahepatic gas increased.
- We constructed an equation for estimation of PMI.
- Our data may provide a useful index of postmortem changes for estimation of PMI.

ABSTRACT

Purpose: Postmortem computed tomography (PMCT) is a useful method to identify various causes of death and measure the volume of internal organs and gases. The purpose of this study was to investigate postmortem changes as measured by PMCT, and the relationship between the volume of organs and gases and postmortem interval (PMI).

Materials and methods: Forty-six cadavers (22 men, 24 women) were examined by CT before autopsy. The volumes of the lungs, intrahepatic gas, and intrarectal gas were measured by CT using a workstation. A stepwise regression analysis was used to establish a predictive equation to ascertain the measured volume using factors including sex, age, height, body mass index (BMI), body surface area (BSA), and PMI. For estimation of PMI, stepwise regression analysis was used.

Results: In the equations for each measured volume, height, diaphragmatic height, and BSA were adopted for the left lung; height and diaphragmatic height were adopted for the right lung; PMI was adopted for intrahepatic gas; and sex and PMI were adopted for intrarectal gas. In the PMI equations, left lung volume, intrahepatic gas, and intrarectal gas were adopted together with sex, weight, and BMI.

Conclusion: Values of intrahepatic and intrarectal gas volumes obtained by PMCT may be useful in investigation of postmortem change. It will be necessary to include other parts of the intestine and to analyze volume changes in gases from these parts after death.

Keywords: Postmortem CT, Postmortem change, Forensic radiology, Organ volume, Postmortem interval

1. Introduction

Postmortem imaging is a useful technique for determining the cause of death in cases of natural death involving no damage to the body surface, or when the bereaved do not wish to have an autopsy performed. Computed tomography (CT) and/or magnetic resonance imaging are mainly performed to derive internal body information. Many reports have confirmed that postmortem imaging is useful in the detection of various causes of death and/or conditions such as the presence of putrefactive gases, pneumothorax with a mediastinal shift, or comminuted fracture [1-3].

Postmortem CT (PMCT) is also useful for measuring the volume of organs or gases. In addition, aortic narrowing and an increase in pleural effusion are reported as postmortem changes observable by CT [4-9].

Forensic pathologists conventionally estimate the postmortem interval (PMI) using early postmortem changes, such as livor mortis and/or rigor mortis. Postmortem changes identified by CT can provide an index for objective estimation of PMI. We measured the volumes of organs and gases in cadavers using our PMCT data and a workstation, to investigate postmortem changes and the relationship between PMI and the volumes of organs and gases.

2. Materials and methods

2.1. Materials

This study was approved by the Kyushu University Institutional Review Board for Clinical Research (No. 27-316). PMCT was conducted on 131 cadavers at Kyushu University, before autopsy, from January 2014 to October 2015. Exclusion criteria were an ambiguous PMI, child (age <16 years), chest trauma, injury to the diaphragm, and pulmonary emphysema. Causes of death included both natural and unnatural. Finally, the study population included 46 cases (22 men, 24 women). For each cadaver, the sex, age, PMI, height, body weight, diaphragmatic height (expressed as costal height at the highest diaphragmatic point), and the weights of the left and right lung and liver were recorded.

2.2. Imaging analysis

PMCT was performed before forensic autopsy using a 16-row multidetector CT scanner (ECLOS, Hitachi Medical Co., Tokyo, Japan). Scan parameters were as follows: 120 kVp; 225 mAs; 1 mm collimation; field of view. A workstation (Aquarius H-Premium SI, Ver4.4.8, Hitachi Medical Co.) was used to measure the volumes of organs and gases. We selected lung volume, intrahepatic gas, and intrarectal gas as our research targets. We defined the rectum as that part of the large intestine from the anus to the sacrum, and intrarectal gas from within this region was measured (Fig. 1). We used the automatic tool of Aquarius H-Premium to calculate the volume of each organ. Each volume measurement was regulated manually as appropriate.

2.3. Statistical analysis

Body mass index (BMI) and body surface area (BSA) were calculated as follows:

BMI (kg/m^2) = body weight (kg)/height^2 (m^2) [10]

BSA (cm^2) = 100.315 × body weight$^{0.383}$ (kg) × height$^{0.693}$ (cm) [11]

All factors and measurements are expressed as mean ± SD values, and the numbers in parentheses show minimum and maximum values. Welch's *t*-test was used to determine differences between men and women. A stepwise regression analysis (forward and backward, $p = 0.25$) was used to establish the predictive equation needed to ascertain lung volume, intrahepatic gas, and intrarectal gas. For each volume equation, we used the parameters sex, age, height, weight, BMI, and BSA (the Six Factors) and PMI. We added diaphragmatic height for lung volume, and liver weight for intrahepatic gas. For estimation of PMI, a stepwise regression analysis was used including the following factors: Six Factors, lung volume, intrahepatic gas, and intrarectal gas. A variance inflation factor (VIF) was calculated, with values exceeding 10 regarded as indicating multicollinearity. All statistical analyses were performed using JMP®, Pro 11.1, Japanese edition (SAS Institute, Inc., Cary, NC).

3. Results

3.1. Descriptive statistics

Descriptive statistics are shown in Table 1. Significant differences were found between men and women regarding height, weight, BSA, left lung volume, and right lung volume. The average age of the cadavers was 61 ± 18.8 years (median age 65 years) and the mean PMI was 34 h (range, 9.5–96 h). Causes of death included traumatic (n = 12), drowning (n = 12), sudden cardiac death (n = 5), hypothermia (n = 3), suffocation (n = 3), drug intoxication (n = 2), and one case each of methomyl intoxication, chronic kidney failure, pneumonia, hypoglycemia, acute pancreatitis, malignant tumor, nervous disease, acute peritonitis, and pulmonary thromboembolism. Two cadavers were excluded from lung volume analysis because of unknown diaphragmatic height owing to adhesions, resulting in the complete examination of only 44 cadavers (20 men, 24 women). Intrahepatic and intrarectal gas volumes were, however, examined in all 46 cases.

3.2. Equations used to estimate lung volume

For the lung volume equations in this study, height, BSA, and diaphragmatic height were adopted for the left lung (adjusted R^2 = 0.55); height and diaphragmatic height were adopted for the right lung (adjusted R^2 = 0.63). However, PMI was not adopted for lung volume (Table 2).

3.3. Equations used to estimate intrahepatic and intrarectal gases

PMI was adopted for the equation used to estimate intrahepatic gas volume (adjusted R^2 = 0.03) (Table 3).

Sex and PMI were adopted for the equation to estimate intrarectal gas volume (adjusted R^2 = 0.09), and both coefficient values were negative (Table 4).

3.4. Equation used for estimating PMI

Sex, weight, BMI, left lung volume, intrahepatic gas, and intrarectal gas were adopted for the equation used to estimate PMI (adjusted R^2 = 0.23). The coefficient values of sex, weight, and intrarectal gas were negative. The root mean square error (RMSE) was 16.4336 (Table 5).

4. Discussion

It was not possible to utilize PMI in the equations for either left or right lung volume in this study. One possible explanation here is that there is no association between lung volume and PMI. Hyodoh et al. reported that there was no statistically significant difference in pulmonary parenchymal volume between two PMCT scans within a particular interval of time [12]. Our findings support their conclusion. Since our study did not consider whether PMI was within 24 h, more useful data could be obtained by studying further cases with PMI established as being within 24 h.

The PMI coefficient value was positive in the equation for the volume of intrahepatic gas, which means that intrahepatic gas increased concomitantly with increase in PMI. However, the adjusted R^2 value was low. This might have occurred because about half of the cases in our study had no or little intrahepatic gas. Christe et al. reported that putrefied cadavers can accumulate gas in the liver [13]. In our study, slight putrefaction was found in all cadavers with only a few days' interval from death to PMCT, so intrahepatic gas volume was low even in cases where it was present. In our study, we did not distinguish between cases with or without cardiopulmonary resuscitation (CPR). Yokota et al. reported that intrahepatic gas is suggestively associated with CPR [14]. It is thought that in cases with slight putrefaction, intrahepatic gas is influenced by CPR. To produce an equation for estimation of intrahepatic gas, we need to examine cases with a longer PMI, and also cases in which CPR was not performed.

One key point of our study is that the coefficient values of sex and PMI were negative for the intrarectal gas volume equation. We selected intrarectal gas because it was easy to extract and measure. It is widely known that intestinal tract gas volume increases after death; however, in our study, intrarectal gas volume tended to decrease. All cadavers in this study had their rectal temperature measured by thermometer at the time of police investigation. In cases with a long PMI, rigor mortis may no longer be present and intrarectal gas readily leaks from the anus. Another consideration is that intestinal tract gas volumes increase after death because of putrefaction, and as intra-abdominal pressure rises, intrarectal gas is pushed out and leaks from the anus. It is therefore necessary to study parts of the intestine that are not affected by external factors. Regarding cadaver gender, there are certain anatomical differences between the sexes regarding the pelvic cavity, such as the prostate and uterus. In addition, the size of skeletal bones varies between the sexes. We should therefore investigate more cases after segregating them by sex.

The PMI equation showed an association with left lung volume, intrahepatic gas, and intrarectal gas, together with sex, weight, and BMI. RMSE was 16.4336, so the PMI equation estimated PMI to within about ±16 h. In the equations used for estimating volume, PMI was adopted for intrahepatic gas and intrarectal gas, but not for the left lung. A question remains as to why only left lung volume was adopted in the equation, but not right lung volume. This can be explained from an anatomical viewpoint. The left lung is located near the stomach and spleen, while the right lung is located near the liver; any potential increase in the volume of the latter, therefore, is somewhat restricted by the solid bulk of the liver. The left lung volume itself could be thought of as an adjustment factor regarding the production of equations to estimate PMI using intrahepatic and intrarectal gas volume.

There are two main limitations in this study. First, it included a small number of cases. It is considered that the relationship between postmortem changes in organs or gases and PMI could be understood more precisely with a greater number of cases. Second, the measurements were performed manually. A program that measures automatically or uniformly using a clear protocol, such as CT values, is thus needed.

In our study, intrahepatic and intrarectal gas volumes tended to increase and decrease, respectively, with postmortem changes. Postmortem changes identified by CT could become a useful tool in the estimation of PMI. We aim to continue this line of research, and would like to determine diachronic postmortem changes on CT images using PMCT.

Conflict of interest

All authors declare that they have no conflict of interest.

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Figure legend

Fig. 1. Left and right lung (a), intrahepatic gas (b), and intrarectal gas (c) were measured manually for each slice. Volumes are marked in green. (d) Virtual reconstruction of a three-dimensional lung image.

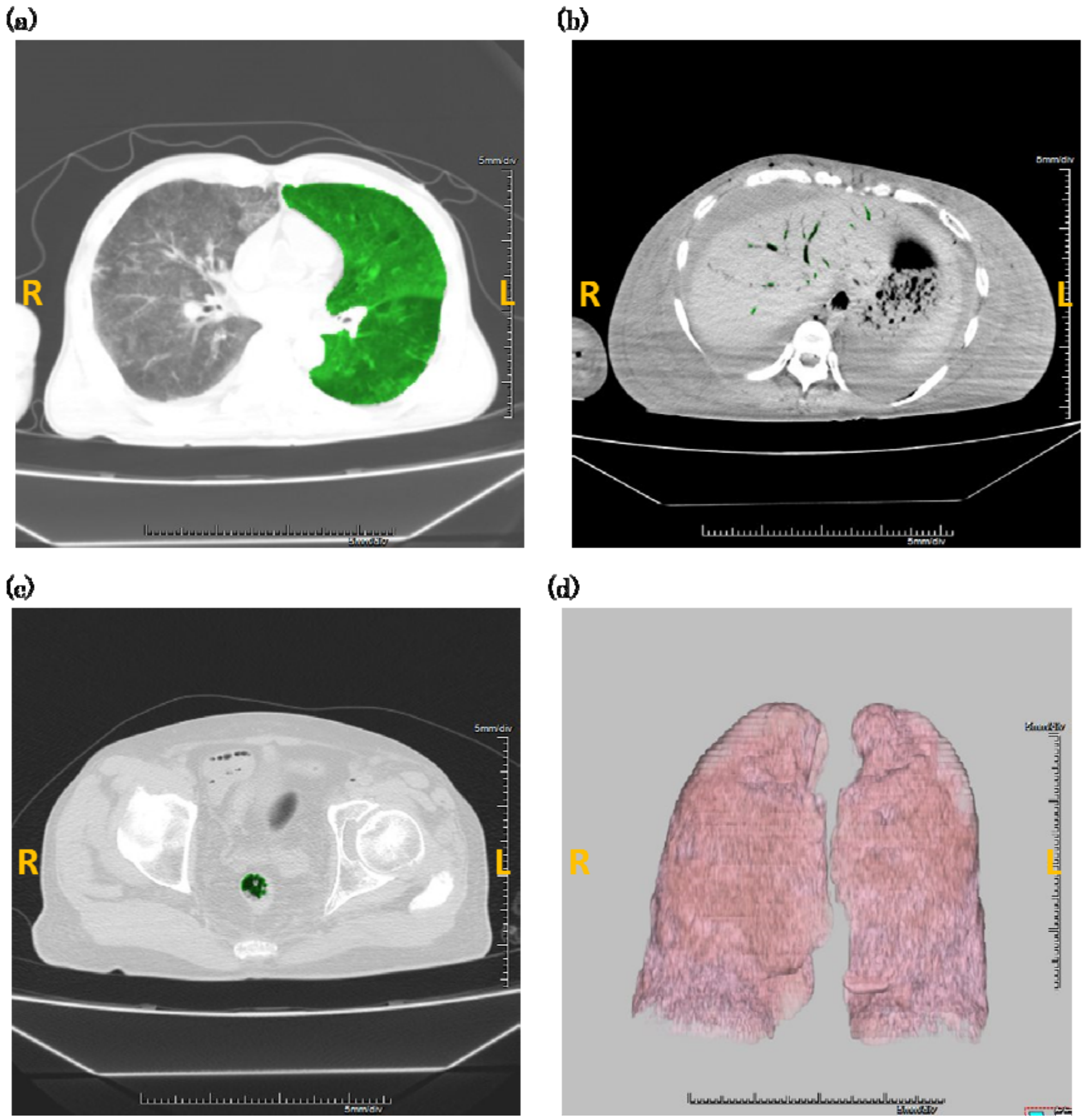

Table 1

Descriptive statistics.

Measurements are expressed as mean ± SD values. The numbers in parentheses show minimum and maximum values.

	Men	Women	*p* value	Total
Number	22	24		46
Age (years)	58.55 ± 18.52 (18-89)	63.25 ± 19.14 (19-87)	0.4016	61 ± 18.79 (18-89)
Height (cm)	164.64 ± 6.90 (152-178)	148.96 ± 7.77 (134-170)	<0.0001	156.46 ± 10.76 (134-178)
Weight (kg)	58.10 ± 9.41 (32.3-78.3)	47.39 ± 12.12 (27.4-76.3)	0.0016	52.51 ± 12.07 (27.4-78.3)
BMI (kg/m^2)	21.42 ± 3.24 (13.27-28.76)	21.20 ± 4.48 (12.84-29.80)	0.847	21.31 ± 3.89 (12.84-29.80)
BSA (cm^2)	16,290 ± 1,306 (12,561-18,340)	14.011 ± 1,768 (11,086-17,776)	<0.0001	15,101 ± 1,928 (11.086-18,340)
PMI (h)	33.18 ± 19.44 (9.5-96)	34.81 ± 17.96 (12-84)	0.7696	34.03 ± 18.49 (9.5-96)
Left lung volume (cm^3)	1207.95 ± 514.46 (476-2081)	794.04 ± 278.73 (365-1359)	0.0014	982.18 ± 449.41 (365-2081)
Right lung volume (cm^3)	1,423.15 ± 571.83 (368-2,621)	1,006.33 ± 314.87 (491-1,739)	0.0059	1,195.80 ± 491.52 (368-2,621)
Intrahepatic gas (cm^3)	8.80 ± 30.45 (0-142)	3.01 ± 6.08 (0-24.3)	0.3905	5.78 ± 21.45 (0-142)
Intrarectal gas (cm^3)	17.58 ± 14.92 (0.67-64.1)	10.64 ± 9.97 (0.59-40)	0.0747	13.96 ± 12.92 (0.59-64.1)

PMI: postmortem interval, BMI: body mass index, BSA: body surface area.

$P < 0.05$ was considered statistically significant.

Table 2

Coefficient value of equations used to estimate lung volume without considering lung weights.

	Left lung	Right lung
Intercept	-4013.196	-3801.717
Sex	-	-
Age	-	-
Height	28.1296	20.3375
Weight	-	-
BMI	-	-
BSA	-0.069	-
Height of diaphragm	327.1052	423.1151
PMI	-	-
Adjusted R^2	0.5475	0.6258

PMI: postmortem interval, BMI: body mass index, BSA body surface area.

Table 3

Coefficient value of equations used to esutimate intrahepatic gas volume.

	Intrahepatic gas
Intercept	-2.7601
Sex	-
Age	-
Height	-
Weight	-
BMI	-
BSA	-
Liver weight	-
PMI	0.251
Adjusted R^2	0.0251

PMI: postmortem interval, BMI: body mass index, BSA: body surface area.

Table 4

Summary of equations used to estimate intrarectal gas volume.

	Intrarectal gas
Intercept	19.6625
Sex	-3.3331
Age	-
Height	-
Weight	-
BMI	-
BSA	-
PMI	-0.1633
Adjusted R^2	0.0873

PMI: postmortem interval, BMI: body mass index, BSA: body surface area.

Table 5

Coefficient value of equations used to estimate PMI.

	PMI
Intercept	10.0487
Sex	-7.1682
Age	-
Height	-
Weight	-1.7257
BMI	5.1377
BSA	-
Left lung	0.0112
Right lung	-
Intrahepatic gas	0.1941
Intrarectal gas	-0.4383
RMSE	16.4336
Adjusted R^2	0.2291

PMI: postmortem interval, BMI: body mass index, BSA: body surface area,

RMSE : Root mean squared error.