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Lung weight estimation with postmortem CT in forensic cases

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ABSTRACT

Postmortem computed tomography (CT) is a minimally invasive technique to examine internal organs before a forensic autopsy. The purpose of our study was to estimate lung weight in a forensic setting in cases of various lung states, including fluid accumulation (congestion, edema, hypostasis, and inflammation etc.) using postmortem CT.

From January 2016 to July 2018, 111 deceased bodies (62 males and 59 females, aged from 18 to 95 (average 59.6) years) were examined by CT before autopsy. Both lungs of the 111 deceased were analyzed separately, making it a total of 222 samples. We extracted lung fields from CT images manually after semi-automatic detection using an image workstation. The total lung volume and 6 categories of lung volume divided according to their CT density were measured. Multiple regression analysis was performed with lung weight in autopsy as the response variable, while the 6 categories were labelled as explanatory variables.

The relation between lung weight in autopsy and lung weight estimated using postmortem CT showed a high Pearson's correlation coefficient (R^2 = 0.9106).

Using postmortem CT, the lung weight can be estimated in forensic settings.

1. Introduction

Currently in Japan, the forensic autopsy rate is low and is performed in only about 11% of all unnatural deaths [1]. With the arrival of a super-aged society, unnatural deaths are increasing, which poses a difficult challenge to increase the rate of autopsies performed. Since postmortem CT is a helpful technique to determine the cause of death, it is widely used for the inspection of the deceased [2,3]. In fact, forensic cases may occasionally be diagnosed solely by postmortem CT findings.

Among the various organs, postmortem CT is especially advantageous in scrutinizing the lungs the because appearance of the lungs changes greatly after death [4], unlike most other organs, which show little change unless in the case of trauma or intrinsic disease. Non-specific causes of death result in congestion or edema of the lungs due to microvascular disruption [5] which is enough to vary their weight. This postmortem lung change can be recognized as hypostasis (dependent opacity) [6,7]. Some causes of death, such as blood loss and hypothermia, exceptionally result in low lung weight or less hypostasis due to less exudate accumulation in the lungs [8,9]. Conversely, in drowning cases, lung weight decreases sequentially after death due to the flowing out of fluid into the thoracic cavity [6,10].

Conventional autopsy is one of the important methods to evaluate the cause of death in the deceased. Along with toxicologic evaluation, it is now a crucial tool to investigate the cause of death in recent years. Organ weight is still one of the main findings in autopsy evaluation [11]. Lung weight is especially thought to be one of the important findings because of its numerical indicators which may reflect the cause of death and/or reflect the agonal period state [5,12]. However, without an autopsy, the lung weight index cannot be measured. Therefore, several trials have been reported using the height, weight, whole body surface area, and body mass index of the deceased to estimate lung weight without an autopsy. However, by using linear

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regression estimation, these categories were unsatisfactory or did not explain the variation of lung weight observed [9,13].

There have been several lung weight estimation trials using CT images [14–16]. These trials aimed to calculate lung weight by using the total lung volume and the mean CT number of the lung. The theory behind their idea was based on the fact that CT numbers and mass density [17] are generally in a linear relationship when falling within a range of lung fields. There were attempts to validate this with animal experiments or surgical specimens [18,19], but whole lung specimens were not examined using deceased bodies. Matoba et al. [20] reported the method of normal aerated lung weight estimation using postmortem CT in autopsy cases. In their results, significant correlation was established between the estimated lung weight and whole dissected lung. On the other hand, poorly aerated lung, due to congestion or edema, is also a common finding in forensic cases. Though it is yet to be investigated, we believe that this method can also be applied to estimate the lung weight in these cases as well.

In this study, the lung weight was estimated using postmortem CT and compared with the lung weight recorded in autopsy. To confirm its reliability, the previously reported methods [18,19] were also compared. These data analyses as well as sample collections and the analyses described below, were performed within the framework of routine medicolegal casework following the autopsy guidelines (2009) and ethics guidelines (2003) of the Japanese Society of Legal Medicine, approved by the institutional ethics committee (No. 16-015).

2. Materials and methods

From January 2016 to July 2018, 949 autopsy cases were enrolled in this study. To minimize the operator dependency, having the same autopsy operator was selected as an inclusion criterion (n = 270). Our exclusion criteria included cases which were as follows: severely corrupted (n = 53), unconfirmed lung weight (severe pleural adhesion) in autopsy (n = 38), found to have prolonged interval between CT and autopsy (more than 6 h) (n = 32), severe putrefaction (n = 26), and less than 18 years old (n = 10). Finally, 111 deceased (62 males and 59 females, age ranging from 18 to 95 (mean 59.6) years, postmortem interval 0.3 to 60 (mean 4.6) days) were included in this study. Both lungs of the 111 deceased were analyzed separately, making it a total of 222 samples.

All deceased were examined by CT using a 16-slice multidetector row CT scanner (Supria, Hitach Corp., Tokyo, Japan) prior to autopsy. The scan parameters were as follows: 120 kV, 215 mA, 0.75 s/rotation, beam pitch 1.3123, collimation 1.25 * 16, slice thickness 5.0 mm.

Standard lung extraction procedure was used in each autopsy and lung weight was measured with a digital scale (MODEL USD-1 VII-WP, Yamato Scale Co., Ltd, Hyogo, Japan). According to the full autopsy, the particular causes of death were diagnosed as follows: drowning (n = 17), hypothermia (n = 15), trauma (n = 14), intoxication (n = 13), cardiac death (n = 7), carbon monoxide poisoning (n = 7), suffocation (n = 7), hanging (n = 4), subdural hematoma (n = 4), abdominal aneurysm (n = 3), death due to fire (n = 3), diabetes mellitus (n = 3), multiple organ failure (n = 3), sleep apnea syndrome (n = 3), adrenal malfunction (n = 1), alcoholic (n = 1), hypo-nutrition (n = 1), pneumonia (n = 1), sub-arachnoid hemorrhage (n = 1), and unknown (n = 2).

Both lung areas were traced by postmortem CT using a semi-automatic lung detection software provided in our image workstation (VINCENT, Fujifilm, Tokyo, Japan). Subsequently, both lung volumes were measured (Fig. 1). Following the reported method [20], the lung volume was divided into 6 categories according to CT number ranges: v1; < −1000 HU volume (ml), v2; −1000 to −700 HU volume (ml), v3; −699 to −200 HU volume (ml), v4; −199 to 0 HU volume (ml), v5; 1–80 HU volume (ml), v6; 81–500 HU volume (ml). The lung area was traced by 2 operators and all the data was revalidated by a clinical radiologist (expert in diagnostic and forensic radiology; 26 & 7 years experience, respectively) to confirm the accuracy of lung detection in postmortem CT.

Multiple regression analysis was performed according to the least square method. The categories were set so that the lungs weight measured in autopsies were labelled as the response variable, and the 6 categories of lung volume based on CT numbers as explanatory variables. If a strong correlation between the explanatory variables was suspected, the combined explanatory variables were selected instead to avoid multiple collinearity. The relation between lung weight in autopsy and estimated lung weight was measured using Pearson's correlation coefficient. In addition, unlike the previously reported method, which utilized a combination of lung volume and lung density to calculate the estimated lung weight, we used the following formula:

Formula A: Lung weight (g) = (Mean CT number (HU) + 1000)/1000 × (lung volume (ml)) [19].

Furthermore, to confirm its validation in a clinical setting, lighter lung weight subjects (up to 300 g) were also compared using estimated lung weight formulas.

For statistical investigation, the JMP version 14.0.0 (SAS Institute, In., North Carolina, USA) software was used along with a regression test and Wilcoxon signed rank test. Differences with $p < 0.05$ were considered to be statistically significant.

3. Results

The results of the autopsies and postmortem CT are presented in Table 1, and the results of the multiple regression analysis which includes all categories (v1 to v6) as explanatory variables is shown in Table 2.

The regression coefficients of v1 was insignificant and presented multicollinearity. This prompted us to remove the v1 volume category from our regression coefficient, while v2, v3, v4, v5, and v6 were selected using stepwise regression analysis as the categories of volume. Each relation with lung weight is presented in Fig. 2. In the multiple regression equation, since the result variable is weight and each explanatory variable is volume, the regression coefficient can consequently be regarded as mass density. In ideal conditions, the CT numbers of v2 (−1000 to −700 HU), v3 (−699 to −200 HU), and v4 (−199 to 0 HU) correspond to 0–0.3 g/cm^3, 0.301–0.8 g/cm^3, and 0.801–1.0 g/cm^3 in mass density, respectively. The regression coefficients of v2, v3, and v4 are within the theoretical ranges of the mass density. Among the variables, v3 (−699 to −200 HU) has the strongest positive correlation, t = 20.45, with lung weight in autopsy which is followed by v4 (−199 to 0 HU), t = 19.73. Thus, v3 and v4, the volume of largely and relatively edematous parts of a lung, are considered to contribute most to lung weight.

The relation between lung weight in autopsy and each category of volume is shown in Fig. 2. Using the stepwise regression method, the estimation equation was estimated by JMP as follows;

Formula (B): Estimated lung weight (g) = 70.910633057 + 0.0586911941 × v2 + 0.4374633191 × v3 + 0.9309684158 × v4 + 1.0354060707 × v5 + 1.0123152027 × v6.

The relation between estimated lung weight and lung weight in autopsy is shown in Fig. 3a (blue as Formula (A), and red as Formula (B)). Pearson's correlation coefficient showed high correlation for both estimations: R^2 was 0.8946 using Formula (A) and 0.9106 using Formula (B). The Wilcoxon signed rank test yielded a statistically significant difference in estimated lung weight between Formula (A) and Formula (B) ($p < 0.005$), and Formula (B) produced a lighter weight estimation (Fig. 3a). The estimated lung weight showed a systematic error with increasingly lighter weight lung (up to 300 g) in both formulas (Fig. 3b).