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Estimating normal lung weight measurement using postmortem CT in forensic cases

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ABSTRACT

Purpose: The aim of this study is to estimate the lung weight using postmortem CT in well aerated lung autopsy cases. The correlation coefficients to the lung weight were also evaluated for the cadavers' height, weight, whole body surface area (WBSA), body mass index, and estimated lung volume.

Materials and methods: From October 2015 to July 2016, 31 cadavers (male 12, female 19, age 20–98 (mean 66.9) y.o., postmortem interval 0.3–75.0 (5.7) days) were compared as regards body weight, height, whole body surface area (WBSA), body mass index (BMI), lung volume on CT, and total lung volume classified into several CT number categories, with their lung weight in autopsy.

Results: The lung weight (mean ± SE) was 284.9 ± 14.8 g in right lung and 249.3 ± 12.9 g in left lung. The %ALV was 79.9 ± 0.9 HU (mean ± standard error (SE)) in both lungs, 80.3 ± 1.3 HU in right lung, and 77.6 ± 2.0 HU in left lung. Using a simple linear regression test, there was no statistically significant correlation between the lung weight and the categories (R^2: body height 0.234, weight 0.224, WBSA 0.309, BMI 0.046, lung volume 0.059). The volume for each individual CT density category showed no significant correlation, but the stepwise regression test yielded an excellent correlation coefficient (R^2 = 0.840).

Conclusion: The well aerated lung weight was 284.9 ± 14.8 g in right lung and 249.3 ± 12.9 g in left lung, and the postmortem CT could estimate the lung weight with high correlation coefficient.

1. Introduction

Postmortem CT imaging has been used for non-distractive examination of cadavers, and it has been thought of as a complementary technique in autopsy [1,2]. In addition, postmortem CT has advantages to detect the cause of death in the investigation of specific lesions, and when the ante-mortem CT image is available to compare, it offers the advantage of being able to compare in the same image modality, which facilitates objective evaluation [3,4]. When the patient has been transferred in an emergency, but not survived, postmortem CT imaging can record the intra-body state as objective findings, and it may bring a wake of find the cause of death. Therefore, it has become widely used in death investigation [1,4,5].

It has been reported that using only postmortem CT could be sufficient to diagnose the cause of death, when comparing to the ante-mortem CT, and so it could be an alternative method of death investigation [6]. In addition, postmortem CT angiography combined with image-guided biopsy could be useful for cause of death investigation when the cadaver had a history of chest pain [7]. Furthermore, an image workstation could enable objective evaluation of the postmortem CT, and the findings could be used to make new discoveries related to the cause of death investigation. For example, lung CT densitometry has several advantages as it is a more quantitative method for estimating lung congestion or dehydration [8].

Conventional autopsy is still one of the important methods to evaluate the cause of death in cadavers, and its macro-/microscopic investigation, in combination with toxicologic evaluation, is the keen fact to evaluate in these years. Among then, organ weight is still one of

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the main findings in autopsy evaluation, especially lung weight. Because the lung weight is affected by the cause of death (or agonal period), it is one of the starting points to death investigation in traditional autopsy. In addition, lung congestion occurs in the normal postmortem passage according to the postmortem interval, so that if lung congestion is not found, in other words the lung weight is very light, it could be an exceptional finding in the autopsy. Empirically, light lung weight is found in some cases, but the reports of lung weight have not excluded the effect on lung edema/congestion in lung weight [9–11].

The lung aeration and congestion/edema can be detected as a lower density or increasing density area, respectively, using CT. But in our literature review, there is no report about the normal aerated lung weight, and also, lung congestion/edema has not been considered when measuring the lung weight. So, if the lung congestive/edematous state could be evaluated by postmortem CT, the normally aerated lung weight could be measured using autopsy lung. In addition, if the CT findings are correlated to the lung weight, the lung weight could be evaluated prior to the autopsy measurement.

In the present study, the lung weight was evaluated from the autopsy record, and compared with postmortem CT. The correlation coefficient to the lung weight for the cadavers' height, weight, whole body surface area (WBSA) [12], body mass index (BMI: body weight (kg)/body height (m^2)), and measured lung volume using postmortem CT were also evaluated. This study was approved by our institutional ethics committee (No. 16-015).

2. Materials and methods

From October 2015 to July 2016, 619 cadavers (male 373, female 242, unknown 4) were examined by postmortem CT and cause of death was evaluated by following full autopsy. Using the volumetry on postmortem CT, the cadavers' lung aeration ratio was evaluated based on the percentage aerated lung (%ALV = 100*(volume of −1000 to −700 HU)/total lung volume). According to the previous reported criteria, more than 70% of %ALV is estimated as normal aerated lung [13]. Using the criteria, 31 cadavers (male 12, female 19, age 20–98 (mean 66.9) y.o., postmortem interval 0.3–75.0 (5.7) days) were enrolled in this study. According to the full autopsy, the various causes of death were as follows: hypothermia n = 11, hypovolemic shock n = 8, cardiac death n = 4, neck hanging n = 3, hyponutrition n = 1, suffocation n = 1, brain contusion n = 1, diabetes mellitus coma n = 1, and alcoholic liver dysfunction n = 1.

All cadavers were examined by CT using a 16-slice multi-detector CT scanner (Supria, Hitachi Corp., Tokyo) just prior to full autopsy (within 1 h). The scan parameters were as follows: 120 kV, 215 mA, 0.75 s/rotation, beam pitch 1.3125, collimation 1.25 × 16, slice thickness 5.0 mm. The lung volume and lung volumes based on CT number categories (less than −1000 HU: lower than aerated lung area, −1000 to −700 HU: aerated lung area, −699 to −200 HU: estimated as less edematous lung area, −199 to 0 HU: estimated as much edematous lung area, 1–80 HU: estimated as organ (tissue) parenchymal area, and 81–500 HU: estimated as blood and/or calcification area) were measured using an image workstation (VINCENT, FujiFilm Tokyo). The image workstation was operated by a single operator to exclude the inspector error.

The standard lung extraction procedure was used in autopsy and the lung weight was measured. The body weight, height, whole body surface area (WBSA), body mass index (BMI), lung volume, and total lung consisting of CT number categories were compared with lung weight using a stepwise correlation method.

For statistical investigation, the JMP (SAS Institute Inc., North Carolina, USA, version 11.0.0) software was used with a regression test. Differences with $p < .05$ were considered to be statistically significant.

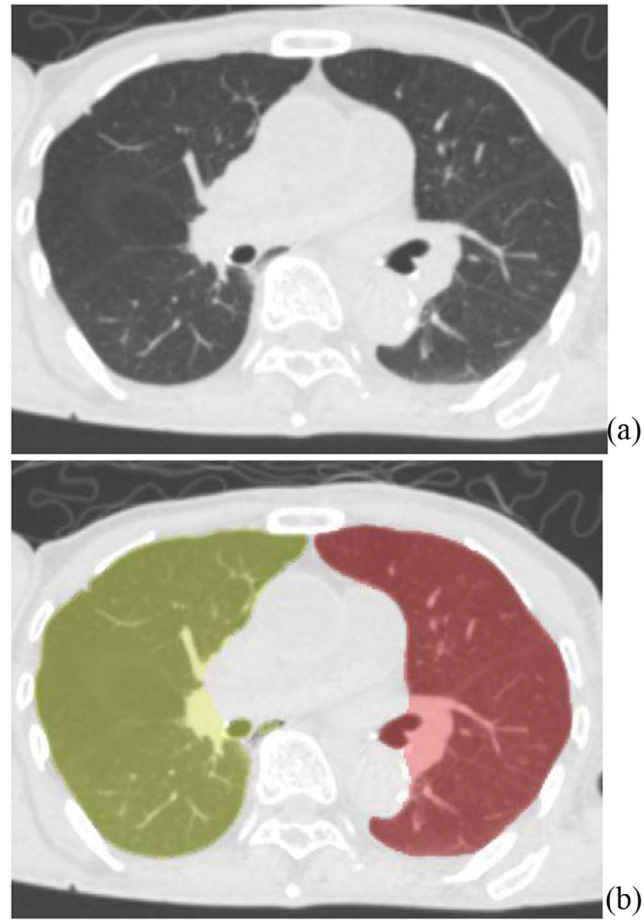

Fig. 1. Postmortem CT image; (a) plain image and (b) selected lung parenchyma in image workstation. The hilum was selected to be concordant with the autopsy procedure. The %ALV of this case presented 86.0% in right lung and 82.5% in left lung. %ALV = 100*(volume of −1000 to −700 HU)/total lung volume.

3. Result

The lung weight (mean ± SE) was 284.9 ± 14.8 g in right lung and 249.3 ± 12.9 g in left lung.

The %ALV were 79.9 ± 0.9% (mean ± standard error (SE)) (in both lungs, 80.3 ± 1.3% in right lung, and 77.6 ± 2.0% in left lung (Fig. 1).

The mean ± SE of height, weight, WBSA, and BMI are presented in Table 1. Using a simple linear regression test, there was no statistically significant correlation between the lung weight and each of the categories.

The volumes by CT density category are presented in Table 2. According to the simple linear regression, there was no significant correlation between the lung weight and each of the CT categories.

Using a stepwise regression test (Table 3), the highest R^2 was 0.8422, and the estimated lung weight could be calculated using the following formula:

$$\text{Estimated lung weight} = 53.4152 + 0.1520*v_1 + 0.8791*v_2 - 0.1123*v_3 + 0.3824*v_4 + 1.1174*v_5 - 0.0936*v_6 - 0.0990*v_7$$

v_1, the estimated lung volume

v_2, the estimated lung volume corresponding to the areas more than −1000 HU

v_3, the estimated lung volume corresponding to the areas from −1000 HU to −700 HU

v_4, the estimated lung volume corresponding to the areas from

Table 1
The statistically correlation between the lung weight and each of the categories using simple linear regression tests.

Category	Height (cm)	Weight (g)	WBSA (m2)	BMI (%)	Lung volume (ml)
Mean ± S.E.	156.5 ± 1.4	43.7 ± 8.6	1.4 ± 0.0	17.8 ± 0.5	1373.9 ± 47.4
R^2	0.234	0.224	0.309	0.046	0.059

There is no statistically significant correlation between the lung weight and each of the categories.
WBSA: whole body surface area.
BMI: body mass index.
S.E.: standard error.
R^2: R-squared value.

−699 HU to −200 HU
v_5, the estimated lung volume corresponding to the areas from −199 HU to 0 HU
v_6, the estimated lung volume corresponding to the areas from 1 HU to 80 HU
v_7, the estimated lung volume corresponding to the areas more than 81 HU

Using the 7 items estimated lung weight formula, the lung weight and estimated lung weight graph is presented in Fig. 2.

4. Discussion

In the literature review, the reference ranges of lung weights were 155–720 g at right lung, 112–675 g at left lung [10], or 1043 g in the underweight group to 1302 g in the obese group [14]. Comparing with these reports, our reported lung weights in autopsy was relatively agreement, with a small error range. Because high aeration of the lung is one of the selection criteria and it was evaluated by postmortem CT, the well aerated lungs were selected objectively in this study. According to our literature review, the lung weight without congestion/edema, which was evaluated objectively, is reported for the first time, so that it will be a key finding in the field of anatomical evaluation and in the evaluation of organ weight in autopsy cases.

In this study, the density of lung parenchyma was classified into 6 categories using CT density to specify the degree of lung congestion/edematous change. Each category presented a different correlation coefficient, with the smallest in aerated lung volume (−1000 to −700 HU) and the highest in congestive lung volume (−199 to 0 HU). In the literature review, the lung weight is mostly dependent on the current fluid content [10,14–19], and it is concordant with our result. Therefore, it was thought that the well aerated lung tissue affected the increasing lung volume, but not so much the lung weight.

The cadavers' height, weight, WBSA, BMI, and measured lung volume by postmortem CT were also compared to the lung weight. But using linear regression estimation, these categories were unsatisfactory for explaining the variation of lung weight. This was concordant with the previous reports [14] that when the stature increases, the lung weight might increase but not linearly. As a result, the lung weight showed no significant correlation to the stature even though the lung parenchyma was well aerated.

In this study, 6 categories were used to minimize the estimating error using correlation coefficient, and the estimated lung weight presented high correlation with lung weight (R^2 = 0.8422). But if different category thresholds were used, different correlation coefficients might be reported. Further examination is needed to determine the best categorization scheme to estimate the lung weight.

Table 3
The statistically correlation between the lung weight and combination of CT items using stepwise regression test.

Item	7	6	5	4	3	2	1
R^2	0.8422	0.8420	0.8417	0.8408	0.8386	0.8218	0.6499

There are high correlations between the lung weight and combination of the CT categories and estimated lung volume. The highest R^2 is 0.8422.
7 items: lung volume, < −1000, −1000 to −700, −699 to −200, −199 to 0, 1–80, 81 < .
6 items: lung volume, < −1000, −1000 to −700, −699 to −200, −199 to 0, 1–80.
5 items: lung volume, < −1000, −699 to −200, −199 to 0, 1–80.
4 items: < −1000, −1000 to −700, −699 to −200, −199 to 0.
3 items: lung volume, −699 to −200, −199 to 0.
2 items: lung volume, −1000 to −700.
1 item: −699 to −200.
R^2: R-squared value.

In postmortem CT, the lung findings change depending on the postmortem intervals, especially in the early period of postmortem interval [20,21]. So, when a postmortem image is evaluated, the PMI should be considered before the image interpretation. In published studies, the lung weight varies greatly according to the individual, and change dramatically depending on aeration and congestion/edematous change [22], so that the lung weights have no meaning in autopsy findings. But in this study, the well aerated lung weight was estimated by postmortem CT image with a high correlation coefficient. Therefore, comparing the autopsy measurement and postmortem CT, the lung fluid volume (congestion/edema) may be expected to be determined numerically. If the lung fluid volume (weight) could be measured in congestive/edematous lung comparing autopsy and postmortem CT, a new approach might be established to investigate the cause of death or to manage cardiopulmonary resuscitation in clinical cases.

Depending on the programming of the image workstation, the evaluation of lung parenchyma was different, and the lung hilum might be included or excluded. In this study, the hilum was selected to be concordant with the autopsy procedures. If only the lung parenchyma was selected for lung volume, the estimated lung weight might be

Table 2
The statistically correlation between the lung weight and each of the CT categories using simple linear regression tests.

Category (HU)	< −1000	−1000 to −700	−699 to −200	−199 to 0	1–80	81 <
Volume (mean ± S.E.) (ml)	0.4 ± 0.2	1086.8 ± 47.9	232.0 ± 10.0	32.3 ± 3.8	18.7 ± 2.2	2.1 ± 0.4
R^2	0.007	N.A.	0.644	0.500	0.369	0.136

There is no significant correlation between the lung weight and each of the CT categories.
S.E.: standard error.
R^2: R-squared value.
N.A.: not available.

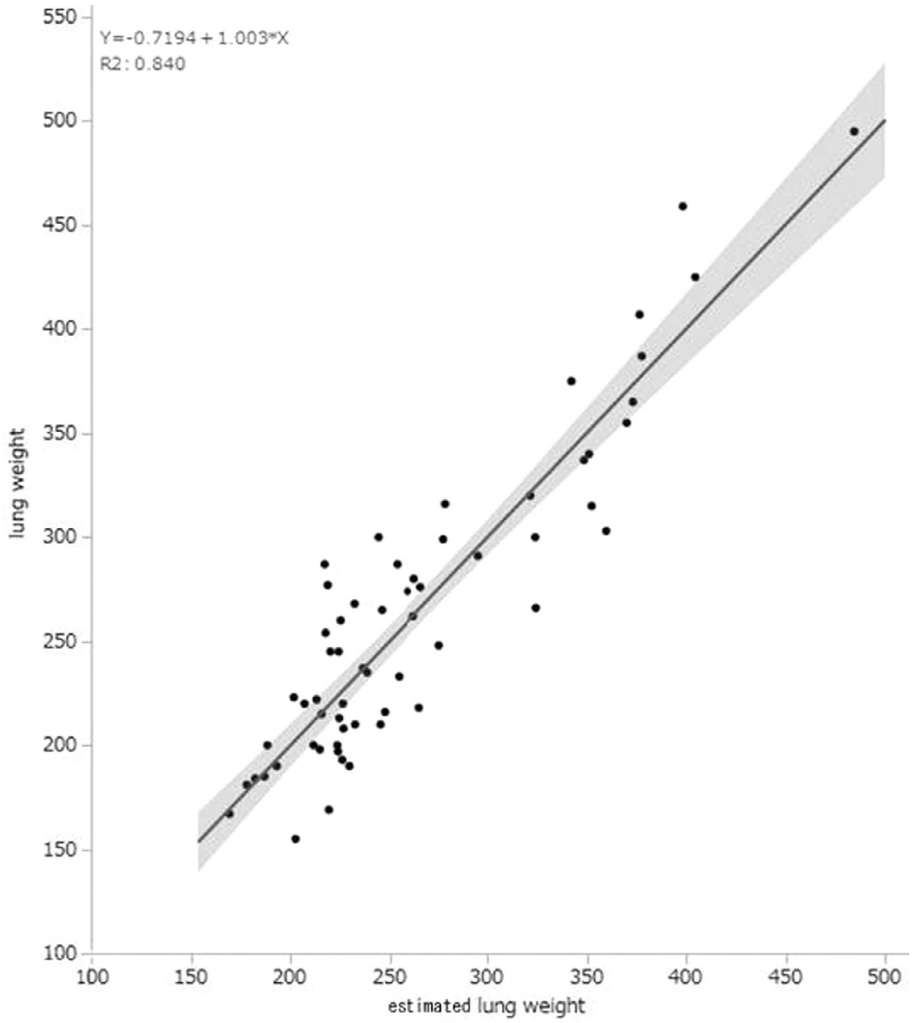

Fig. 2. Relations between the lung weight and estimated lung weight. The correlation was excellent, with a correlation coefficient of 0.840. Grey area: 95% equal precision band.

different. Even in virtual autopsy on postmortem CT, the same approach (procedure) would be necessary to compare with the autopsy dissected lung parenchyma.

This study had some limitations. First, the number of subjects was limited, because the inclusion criteria required well aerated lung cadaver in autopsy (%ALV more than 70%). Even though well aerated lung on postmortem CT was selected in autopsy cases, the average postmortem interval was 5.7 days, so that the postmortem change might have affected the lung.

Second, because of our exclusion criteria, this study has not evaluated the congestive/edematous lung. It was thought that the lung congestion/edematous change increases in postmortem lung parenchyma, so the categories of CT density might be changed, and it would affect the correlation coefficient. Further study will be needed to evaluate a greater variety of congestion/edematous lungs to compare the lung weight and postmortem lung CT.

Third, the population of this study had no young aged cadaver (less than 18-year-old). We haven't examined whether the estimated lung formula can be used for young-aged cadavers' lung weight. Because the organs are growing during youth, the balance between the lung weight increase and the lung volume increase might affect the correlation coefficient.

Fourth, the lung hypostasis may change depending on the cause of death [23]. In this study, the estimated lung weight has not been evaluated as regards how useful it may be to estimate the cause of death. The authors have expected that using this estimated lung weight method could be the first step to estimate the lung fluid (congestion/edema) volume, and it may be a new approach to evaluate the cause of death and/or CPR related effect in cadavers. In addition, even in living patients, the lung edematous change could be evaluated numerically, and it may possibly be one index to use in selecting treatment.

5. In conclusion

We could select well aerated lungs using postmortem CT and the lung weight was 284.9 ± 14.8 g in right lung and 249.3 ± 12.9 g in left lung. The estimated lung weight yielded a high correlation coefficient to the lung weight, and postmortem CT could estimate the lung weight.

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