CrossMark

ORIGINAL ARTICLE

Comparison of volume and attenuation of the spleen between postmortem and antemortem computed tomography

Hidemi Okuma[1] · Wataru Gonoi[1] · Masanori Ishida[2] · Go Shirota[1] · Shigeaki Kanno[1] ·
Yukako Shintani[3] · Hiroyuki Abe[3] · Masashi Fukayama[3] · Kuni Ohtomo[1]

Abstract

Objectives The purpose of this study is to compare the postmortem changes in computed tomography (CT) findings between normal spleen, splenic infarct, and splenic tumor infiltration.

Methods The institutional review board approved this study, and informed consent was obtained from the next of kin. We studied 63 consecutive subjects who underwent antemortem CT, postmortem CT, and autopsy between February 2012 and December 2013. Postmortem CT was performed within 1678 min after death and was followed by pathological studies. The subjects were divided into three groups based on the pathological findings: normal, splenic infarct, and splenic tumor infiltration. The volume and attenuation of the spleen were compared between antemortem and postmortem CT using paired *t* tests. Gender, age, time elapsed since death, and the causes of death were examined as potential confounding factors of the postmortem changes in volume and attenuation.

Results In all groups, the spleen decreased in volume and attenuation increased on postmortem CT compared with antemortem CT. The postmortem changes in spleen volume and attenuation were not significantly associated with sex, age, time elapsed since death, or causes of death.

Conclusions Spleen volume decreased and attenuation increased on postmortem CT compared with antemortem CT in subjects with a normal spleen, splenic infarct, or splenic tumor infiltration. These results should caution us against underestimating the significance of splenomegaly on postmortem CT, misinterpreting reduced splenic volume as the presence of hypovolemic or distributive shock in the subject while alive, and confusing postmortem splenic hyperattenuation with diseases characterized by this finding.

Keywords Forensic radiology · Postmortem computed tomography · Postmortem changes · Forensic medicine · Spleen

Introduction

High-resolution imaging modalities such as computed tomography (CT) and magnetic resonance imaging are increasingly being used as adjuncts to traditional forensic methods in postmortem studies [1–5]. However, clinical radiologists may experience difficulty interpreting postmortem images because there are specific and nonspecific postmortem signs [6]. As guidelines for the diagnosis of postmortem images are now being established worldwide, it is important to understand the appearances of normal changes on postmortem CT [7]. The postmortem CT features of several organs, including the cardiovascular system [8–11], brain [12], thyroid [13], adrenal gland [14], muscle [15], airway [16], and lung [17], have already been described. To our knowledge, however, there are no reports describing the postmortem changes of the spleen between antemortem and postmortem images.

✉ Wataru Gonoi
    watapi-tky@umin.net

[1] Department of Radiology, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan

[2] Department of Radiology, Mutual Aid Association for Tokyo Metropolitan Teachers and Officials, Sanraku Hospital, 2-5 Kandasurugadai, Chiyoda-ku, Tokyo 101-8326, Japan

[3] Department of Pathology, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan

Therefore, it is difficult to identify postmortem changes in a diseased spleen when the normal changes in the spleen on postmortem CT have not been documented. The objectives of this study were to document the normal changes that occur postmortem in the spleen and to compare these with the postmortem changes in the case of splenic infarct and splenic tumor infiltration. To achieve these objectives, we conducted a quantitative study in and compared splenic volume and splenic attenuation between postmortem and antemortem CT scans obtained in the same subjects.

Materials and methods

The institutional review board approved this study, and written informed consent was obtained from the subject's next of kin to use the clinical, pathological, and radiographic data in this study.

Study design and subjects

Consecutive subjects who died from nontraumatic causes in our academic tertiary care hospital and who underwent unenhanced upper abdominal antemortem CT, postmortem CT, and autopsy between February 2012 and December 2013 were retrospectively enrolled. Potential subjects were excluded for the following reasons: age <20 years, treatment with cardiopulmonary resuscitation, and prior splenectomy. The subjects were divided into three groups based on their pathological findings: normal spleen, splenic infarct, and splenic tumor infiltration. All cadavers were carefully transported on a stretcher and were kept in the supine position at room temperature from the time of death until postmortem CT.

Antemortem CT imaging

All antemortem upper abdominal CT scans were obtained without contrast medium using a 64-detector-row helical CT scanner (Aquilion 64, Toshiba Medical Systems Corporation; Discovery CT750 HD and LightSpeed VCT, GE Healthcare) or a 320-detector-row helical CT scanner (Aquilion ONE, Toshiba Medical Systems Corporation), in the craniocaudal direction with the subject in the supine position with both arms raised. The scan parameters were as follows: slice thickness, 5 mm; slice interval, 5 mm; rotation time, 0.5 s; and tube voltage, 120 kVp. Automatic tube current modulation was performed using Volume EC (Toshiba) and AutomA (GE). Images were reconstructed at 0.5 mm intervals with a 350-mm field of view and a 512×512 image matrix.

Postmortem CT imaging

Whole-body postmortem CT studies were obtained without contrast medium using a 4-detector-row CT scanner (Robusto, Hitachi Medical Corporation) in helical mode in the craniocaudal direction. For all scans, the cadaver was laid in the supine position with arms placed on either side of the body. The scan parameters were as follows: slice thickness, 2.5 mm; slice interval, 1.25 mm; rotation time, 0.5 s; tube voltage, 120 kVp; and tube current, 250 mA. Images were reconstructed at 1.25 mm intervals with a 350-mm field of view and a 512×512 image matrix.

Image interpretation

All images were interpreted by a board-certified radiologist (6 years of experience) who was not provided with clinical information. The postmortem and most recent antemortem CT images were compared. CT images were reviewed on a two-dimensional workstation (OsiriX, Pixmeo Inc.). We measured splenic volume (in cm³) and attenuation (in Hounsfield units, HU) by manually contouring the spleen as the region of interest (ROI) on each slice the spleen was observed. Accessory spleens were not measured. We then calculated the total volume and the mean splenic attenuation using the OsiriX three-dimensional ROI tool.
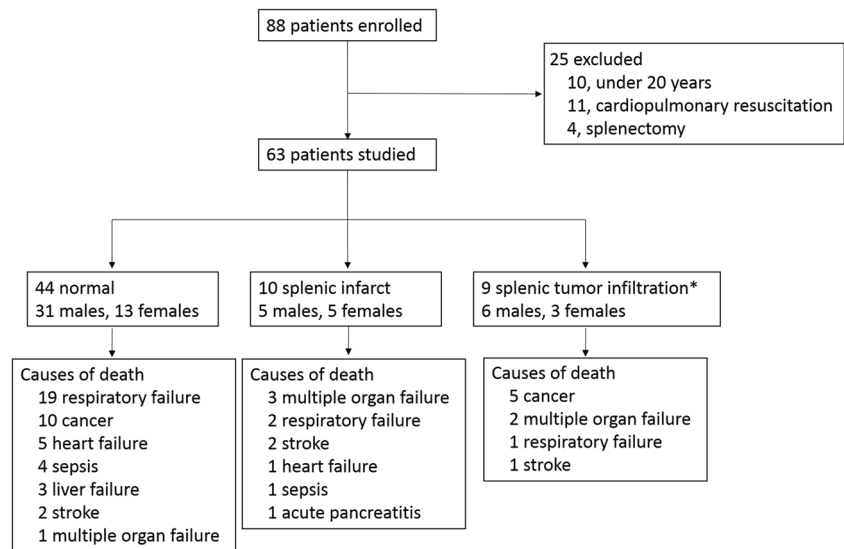
Pathological analysis

The subjects were divided into three groups based on the following pathological findings: normal spleen, splenic infarct, or splenic tumor infiltration (including tuberculoid granuloma). Normal spleen was defined as the absence of gross pathological findings and space-consuming lesions. Tiny benign lesions, such as cysts and calcified granulomas, were classified as normal. The pathological diagnosis of splenic infarct or splenic tumor infiltration was confirmed microscopically if it was uncertain on macroscopic autopsy or postmortem CT. The cause of death was determined based on the subject's antemortem clinical course and the postmortem pathological findings.

Statistical analyses

We compared the differences in volume and splenic attenuation between antemortem CT and postmortem CT using paired t tests. The postmortem changes in volume and splenic attenuation were calculated as the ratio of volume and splenic attenuation on postmortem CT to that on antemortem CT. Simple linear regression was used to analyze the correlation between the autopsy weight and the postmortem CT volume of the spleen. Significant differences among the three groups (normal spleen, splenic infarct, and splenic tumor infiltration

Fig. 1 Subject disposition.
*Of the nine patients with splenic tumor infiltration, the pathology reports stated that the spleen was infiltrated by lymphoid tumor in five subjects, by metastases of the original tumor in three subjects (one each of hepatocellular carcinoma, pancreatic cancer, and renal pelvic cancer), and by tuberculoid granuloma in one subject

88 patients enrolled

25 excluded
 10, under 20 years
 11, cardiopulmonary resuscitation
 4, splenectomy

63 patients studied

44 normal
31 males, 13 females

10 splenic infarct
5 males, 5 females

9 splenic tumor infiltration*
6 males, 3 females

Causes of death
 19 respiratory failure
 10 cancer
 5 heart failure
 4 sepsis
 3 liver failure
 2 stroke
 1 multiple organ failure

Causes of death
 3 multiple organ failure
 2 respiratory failure
 2 stroke
 1 heart failure
 1 sepsis
 1 acute pancreatitis

Causes of death
 5 cancer
 2 multiple organ failure
 1 respiratory failure
 1 stroke

groups) were determined using the Kruskal–Wallis test. We used unpaired t tests to analyze the postmortem changes in splenic volume and attenuation between sexes and linear least squares regression to examine the effects of age and the time elapsed since death on splenic volume and attenuation. The Kruskal–Wallis test was used to determine the association between the cause of death and the postmortem changes in splenic volume and attenuation in each of the three groups (normal spleen, splenic infarct, and splenic tumor infiltration groups). The level of statistical significance was set at 0.05. All statistical analyses were performed using R version 3.0 (The R Foundation for Statistical Computing).

Results

A total of 88 consecutive subjects were initially enrolled in this study. After applying the exclusion criteria, 63 adults (42 males, 21 females) were included in this study (Fig. 1). The mean age at death was 67 years (range, 39–90 years; median, 68 years). Antemortem CT was performed at a median of 23 days before death (range, 1–246 days). Postmortem CT

was performed at a median of 4.8 h after death (range, 1.5–28 h) and was immediately followed by autopsy.

The subjects were divided into three groups based on their pathological findings: normal spleen ($n=44$; 31 males, 13 females), splenic infarct ($n=10$; 5 males, 5 females), and splenic tumor infiltration ($n=9$; 6 males, 3 females). Of the nine subjects with splenic tumor infiltration, the pathology reports stated that the spleen was infiltrated by lymphoid tumor in five subjects, by metastases of the original tumor in three subjects (one each of hepatocellular carcinoma, pancreatic cancer, and renal pelvic cancer), and by tuberculoid granuloma in one subject. The causes of death were respiratory failure ($n=19$), cancer ($n=10$), heart failure ($n=5$), sepsis ($n=4$), liver failure ($n=3$), stroke ($n=2$), and multiple organ failure ($n=1$) in the normal spleen group; multiple organ failure ($n=3$), respiratory failure ($n=2$), stroke ($n=2$), heart failure ($n=1$), sepsis ($n=1$), and acute pancreatitis ($n=1$) in the splenic infarct group; and cancer ($n=5$), multiple organ failure ($n=2$), respiratory failure ($n=1$), and stroke ($n=1$) in the splenic tumor infiltration group. There were no cases of sudden death or hemorrhagic shock. No apparent gas was found in the spleen on antemortem CT, postmortem CT, or at autopsy.
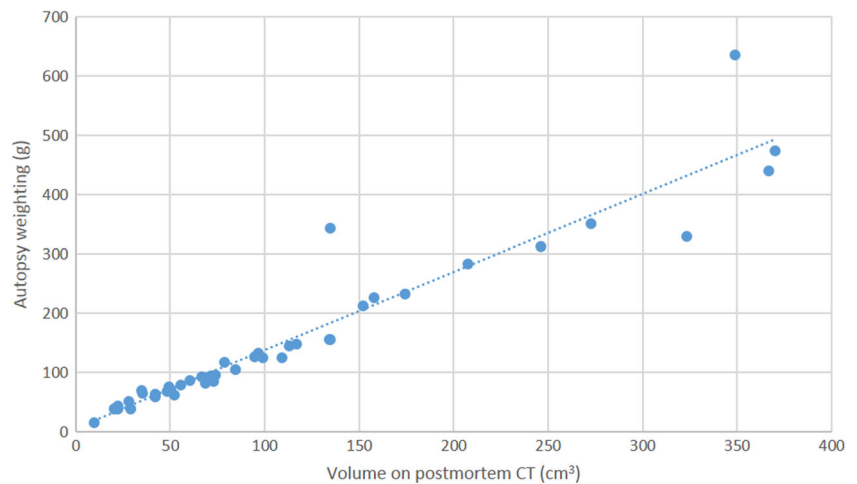
Table 1 Comparison of splenic volume between antemortem and postmortem CT scans

	Normal group	Splenic infarct group	Splenic tumor infiltration group
Antemortem volume (cm^3)	161.8 ± 175.8	179.4 ± 213.4	234.4 ± 186.8
Postmortem volume (cm^3)	110.9 ± 96.9	138.8 ± 170.3	166.5 ± 171.7
P value[a]	<0.01	0.20	0.03
Postmortem/antemortem ratio	0.80 ± 0.31	0.95 ± 0.38	0.70 ± 0.24

Values are presented as the mean ± standard deviation.

[a] Splenic volume was compared between the antemortem and postmortem CT scans using paired t tests.

Fig. 2 Volume on postmortem CT versus autopsy weight. A simple linear regression analysis revealed a significant correlation between the measured volume on postmortem CT and the autopsy weight ($P < 0.001$, $R = 0.95$). The autopsy weight of the spleen (W) can be calculated from the volume on postmortem CT (V) as follows: $W = (1.3 \times V) + 6.1$

The splenic volumes (cm^3) on antemortem and postmortem CT are summarized in Table 1 according to the pathological group. Splenic volume was significantly less on postmortem CT than on antemortem CT in the normal ($P < 0.01$) and splenic tumor infiltration ($P = 0.03$) groups. In the splenic infarct group, the spleen tended to be smaller on postmortem CT than on antemortem CT, although the difference was not statistically significant. There were no significant differences among the three groups in terms of splenic volume between antemortem and postmortem CT ($P = 0.20$).

The splenic volumes on postmortem CT and the autopsy weights of the spleens are shown in Fig. 2. The mean ± standard deviation weight of the autopsy specimens was 154.1 ± 134.8 g. A simple linear regression analysis revealed a significant correlation between the measured volume on postmortem CT and the autopsy weight ($P < 0.001$, $r = 0.95$). The autopsy weight of the spleen (W) could be calculated from the volume determined on postmortem CT (V) as follows: $W = (1.3 \times V) + 6.1$.

The CT attenuation values (in HU) of the spleen on antemortem and postmortem CT are listed in Table 2. The spleen showed significantly higher attenuation on postmortem CT than on antemortem CT in the normal ($P < 0.001$) and splenic

tumor infiltration ($P = 0.03$) groups. In the splenic infarct group, splenic attenuation tended to be higher on postmortem CT than on antemortem CT, although the difference was not statistically significant. There were no significant differences among the three groups in terms of CT attenuation values between antemortem and postmortem CT ($P = 0.59$).

There was no statistically significant association between sex and postmortem change in splenic volume or splenic attenuation in any group (Table 3).

Table 4 shows the results of correlation analysis for postmortem change in splenic volume and splenic attenuation with each of age and the time elapsed since death. Only the splenic tumor infiltration group showed a statistically significant positive correlation between splenic volume ratio and age ($P < 0.01$, $r = 0.81$). Splenic volume was not correlated with age in either the normal or splenic infarct groups. Furthermore, the splenic volume ratio was not significantly correlated with the time elapsed since death in any group, and splenic attenuation was not correlated with age or time elapsed since death in any group. The cause of death was not significantly associated with the postmortem changes in splenic volume or splenic attenuation in any group (Table 5).

Table 2 Comparison of splenic attenuation between antemortem and postmortem CT scans

	Normal group	Splenic infarct group	Splenic tumor infiltration group
Antemortem attenuation (HU)	46.8 ± 9.2	48.0 ± 9.4	44.5 ± 5.9
Postmortem attenuation (HU)	54.3 ± 12.4	50.7 ± 9.9	52.9 ± 7.0
P value[a]	<0.001	0.46	0.03
Postmortem/antemortem ratio	1.17 ± 0.25	1.08 ± 0.25	1.17 ± 0.25

Values are presented as the mean ± standard deviation

HU Hounsfield units

[a] Splenic attenuation was compared between the antemortem and postmortem CT scans using paired *t* tests

Table 3 Associations of splenic volume and attenuation with sex

	Splenic volume			Splenic attenuation		
	Male	Female	P value [a]	Male	Female	P value [a]
Normal group	0.78 ± 0.30	0.86 ± 0.33	0.46	1.17 ± 0.24	1.19 ± 0.28	0.79
Splenic infarct group	0.78 ± 0.37	1.13 ± 0.34	0.16	0.97 ± 0.23	1.18 ± 0.24	0.20
Splenic tumor infiltration group	0.67 ± 0.23	0.76 ± 0.31	0.69	1.23 ± 0.19	1.15 ± 0.35	0.72

Values are presented as the mean ± standard deviation

[a] Unpaired t tests were used to compare splenic volume and splenic attenuation between males and females

Discussion

The normal splenic weight in the adult is approximately 100–150 g based on operative specimens and autopsy material [18, 19], and the normal splenic volume is approximately 200–220 cm^3 [20–22]. However, the weight or volume of an excised spleen differs from that in vivo, owing to several factors, such as the amount of entrapped blood, circulatory factors during surgery, the duration of vessel clamping, and uncontrolled blood loss from the specimen before it is weighed [23]. We do not need to worry about circulatory factors during surgery or the duration of vessel clamping in cadavers, but the amount of entrapped blood and uncontrolled blood loss from the specimen before it is weighed could affect the splenic weight recorded at autopsy. In this study, we compared the splenic volume on postmortem CT with the splenic weight at autopsy in the same subjects, where autopsy was promptly performed after postmortem CT. The strong positive correlation between the splenic volume on postmortem CT, and the splenic weight measured at autopsy indicates that the weight of the spleen can be estimated from the splenic volume measured on postmortem CT. In the present study, some outliers can be seen in Fig. 2, and these are likely due to an excessive amount of entrapped blood or uncontrolled blood loss from the specimen.

We found a reduction in splenic volume on postmortem CT compared with antemortem CT in all three groups. The splenic

volume decreases in hypovolemic or distributive shock [24, 25]. Because death is the ultimate state of hypovolemic or distributive shock, with the cessation of blood flow and a drop in circulatory pressure to approximately 7 mmHg [26, 27], it is reasonable to expect a postmortem reduction in splenic volume, as was observed in our study.

The present results show that splenic attenuation was higher on postmortem CT than on antemortem CT in all of the three groups. Postmortem clotting and sedimentation of blood components may explain the higher attenuation of the spleen on the postmortem images. However, these phenomena usually form layered structures or horizontal planes, owing to the effects of gravity [28], but no clear layers or obvious differences in attenuation between ventral and dorsal sites in the spleen were observed in our subjects. It is possible that the serous component leaked from the spleen and the concentrated blood left in the spleen caused higher attenuation on postmortem CT. However, the attenuation of blood on postmortem CT is similar to that on antemortem CT [29]. Thus, postmortem changes of the blood itself are unlikely to explain the higher splenic attenuation on postmortem CT.

Because attenuation is determined by the physical density of an object [30], higher attenuation on postmortem CT indicates that the splenic components have a higher density after death than during life. The spleen has a rich blood flow, so we can assume that it loses blood and becomes more compact at death, leading to the higher attenuation on postmortem CT.

Autolysis could have contributed to the postmortem changes observed in the spleen in our study. Although autolysis is known to occur during agonal stage [31–33], CT evidence of

Table 4 Correlation of splenic volume and attenuation with age and time elapsed since death

	Splenic volume		Splenic attenuation	
	Age	Time elapsed since death	Age	Time elapsed since death
Normal group	0.45	0.37	0.42	0.72
Splenic infarct group	0.20	0.97	0.36	0.78
Splenic tumor infiltration group	<0.01	0.57	0.40	0.96

P values are shown and were determined by linear least squares regression

Table 5 Associations of splenic volume and attenuation with the cause of death

	Volume	Attenuation
Normal group	0.15	0.21
Splenic infarct group	0.17	0.13
Splenic tumor infiltration group	0.12	0.23

P values are shown and were determined using the Kruskal–Wallis test

autolysis generally appears later than 24–48 h after death [28]. In the present study, postmortem CT was performed within 28 h after death, which is outside the timing of visualization of autolysis. Accordingly, the present results show no significant associations between the postmortem changes in splenic volume or attenuation and the time elapsed since death at 1.5–28 h after death.

We also investigated possible confounding factors of postmortem changes such as sex, age, and the cause of death. Although a positive association between splenic volume and age was observed in the splenic tumor infiltration group, the reason for this is uncertain. Otherwise, there were no statistically significant associations between the confounding factors of sex, age, or cause of death with the postmortem changes in splenic volume or splenic attenuation. Overall, these results indicate that volume reduction and splenic hyperattenuation are general postmortem findings regardless of sex, age, cause of death, or the presence of splenic diseases such as infarct and tumor infiltration.

As mentioned above, it is common to observe a small spleen under the condition of hypovolemic or distributive shock in life. However, we cannot conclude that a subject died from hypovolemic or distributive shock based on the postmortem CT finding of a reduced splenic volume because the healthy spleen loses volume postmortem. We also need to bear in mind that we may underestimate or even do not notice splenomegaly, especially in cases of splenic tumor infiltration in which the splenic volume decreases more than normal after death.

Splenic calcification, haemochromatosis [34], and Thorotrast accumulation [35, 36] are known to cause splenic hyperattenuation in life, and this finding is not specific to postmortem changes. However, if no comparable antemortem CT images are available in the same subject, then we should consider that splenic hyperattenuation on postmortem CT is a normal postmortem change rather than evidence of an underlying disease.

Our study has some limitations. First, interscanner variability of the CT attenuation values should be considered [37, 38] because we used several different CT scanners. However, recent technological innovations have greatly decreased the effect of scanner variability [39], and we standardized the tube voltage at 120 kVp for this reason. Second, it is possible that underlying diseases or cadaver storage might contribute to the postmortem differences [40, 41]. However, these factors are unlikely to affect our conclusions because we separated subjects with splenic diseases from those with a normal spleen based on the pathological findings, and all of the cadavers were preserved at our hospital in the same place, at the same temperature, and in the same position.

In conclusion, our study showed a reduction in splenic volume and splenic hyperattenuation on postmortem CT images compared with antemortem CT images in subjects divided into normal, splenic infarct, and splenic tumor infiltration groups. These results suggest that, when interpreting postmortem CT, especially in subjects with splenic tumor infiltration, it is important to avoid underestimating splenomegaly, misinterpreting reduced splenic volume as a condition of hypovolemic or distributive shock while alive, and mistaking normal findings for those of a disease process depicted by splenic hyperattenuation.

References

1. Thali MJ, Yen K, Schweitzer W et al (2003) Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI)—a feasibility study. J Forensic Sci 48:386–403

2. O'Donnell C, Woodford N (2008) Post-mortem radiology—a new sub-speciality? Clin Radiol 63:1189–94. doi:10.1016/j.crad.2008.05.008

3. Cha JG, Kim DH, Kim DH et al (2010) Utility of postmortem autopsy via whole-body imaging: initial observations comparing MDCT and 3.0 T MRI findings with autopsy findings. Korean J Radiol 11:395–406. doi:10.3348/kjr.2010.11.4.395

4. Roberts IS, Benamore RE, Benbow EW et al (2012) Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet 379:136–42. doi:10.1016/s0140-6736(11)61483-9

5. Flach PM, Thali MJ, Germerott T (2014) Times have changed! Forensic radiology—a new challenge for radiology and forensic pathology. AJR Am J Roentgenol 202:W325–34. doi:10.2214/ajr.12.10283

6. Christe A, Flach P, Ross S et al (2010) Clinical radiology and postmortem imaging (Virtopsy) are not the same: specific and unspecific postmortem signs. Leg Med (Tokyo) 12:215–22. doi:10.1016/j.legalmed.2010.05.005

7. Ishida M, Gonoi W, Okuma H et al (2015) Common postmortem computed tomography findings following atraumatic death: differentiation between normal postmortem changes and pathologic lesions. Korean J Radiol 16:798–809. doi:10.3348/kjr.2015.16.4.798

8. Ishida M, Gonoi W, Hagiwara K et al (2011) Hypostasis in the heart and great vessels of non-traumatic in-hospital death cases on postmortem computed tomography: relationship to antemortem blood tests. Leg Med (Tokyo) 13:280–5. doi:10.1016/j.legalmed.2011.09.004

9. Ishida M, Gonoi W, Hagiwara K et al (2011) Intravascular gas distribution in the upper abdomen of non-traumatic in-hospital death cases on postmortem computed tomography. Leg Med (Tokyo) 13:174–9. doi:10.1016/j.legalmed.2011.03.002

10. Okuma H, Gonoi W, Ishida M et al (2013) Heart wall is thicker on postmortem computed tomography than on antemortem [corrected]

computed tomography: the first longitudinal study. PLoS ONE 8: e76026. doi:10.1371/journal.pone.0076026

11. Okuma H, Gonoi W, Ishida M et al (2014) Greater thickness of the aortic wall on postmortem computed tomography compared with antemortem computed tomography: the first longitudinal study. Int J Legal Med 128:987–93. doi:10.1007/s00414-013-0955-z

12. Shirota G, Gonoi W, Ishida M et al (2015) Brain swelling and loss of gray and white matter differentiation in human postmortem cases by computed tomography. PLoS ONE 10:e0143848. doi:10.1371/journal.pone.0143848

13. Ishida M, Gonoi W, Hagiwara K et al (2011) Postmortem changes of the thyroid on computed tomography. Leg Med (Tokyo) 13:318–22. doi:10.1016/j.legalmed.2011.08.003

14. Ishida M, Gonoi W, Hagiwara K et al (2014) Early postmortem volume reduction of adrenal gland: initial longitudinal computed tomographic study. Radiol Med. doi:10.1007/s11547-014-0449-1

15. Okuma H, Gonoi W, Ishida M et al (2014) Comparison of attenuation of striated muscle between postmortem and antemortem computed tomography: results of a longitudinal study. PLoS ONE 9: e111457. doi:10.1371/journal.pone.0111457

16. Ishida M, Gonoi W, Hagiwara K et al (2014) Fluid in the airway of nontraumatic death on postmortem computed tomography: relationship with pleural effusion and postmortem elapsed time. Am J Forensic Med Pathol 35:113–7. doi:10.1097/paf.0000000000000083

17. Arthurs OJ, Guy A, Kiho L, Sebire NJ (2015) Ventilated postmortem computed tomography in children: feasibility and initial experience. Int J Legal Med 129:1113–20. doi:10.1007/s00414-015-1189-z

18. Cools L, Osteaux M, Divano L, Jeanmart L (1983) Prediction of splenic volume by a simple CT measurement: a statistical study. J Comput Assist Tomogr 7:426–30

19. Kumar V, Abbas A, Fausto N, Aster J. (2010) Diseases of white blood cells, lymph nodes, spleen and thymus. 8th ed. Saunders Philadelphia

20. Caglar V, Alkoc OA, Uygur R, Serdaroglu O, Ozen OA (2014) Determination of normal splenic volume in relation to age, gender and body habitus: a stereological study on computed tomography. Folia Morphol (Warsz) 73:331–8. doi:10.5603/fm.2014.0038

21. Henderson JM, Heymsfield SB, Horowitz J, Kutner MH (1981) Measurement of liver and spleen volume by computed tomography. Assessment of reproducibility and changes found following a selective distal splenorenal shunt. Radiology 141:525–7. doi:10.1148/radiology.141.2.6974875

22. Prassopoulos P, Daskalogiannaki M, Raissaki M, Hatjidakis A, Gourtsoyiannis N (1997) Determination of normal splenic volume on computed tomography in relation to age, gender and body habitus. Eur Radiol 7:246–8. doi:10.1007/s003300050145

23. Strijk SP, Wagener DJ, Bogman MJ, de Pauw BE, Wobbes T (1985) The spleen in Hodgkin disease: diagnostic value of CT. Radiology 154:753–7. doi:10.1148/radiology.154.3.3969481

24. Risoe C, Hall C, Smiseth OA (1991) Blood volume changes in liver and spleen during cardiogenic shock in dogs. Am J Physiol 261: H1763–8

25. Risoe C, Tan W, Smiseth OA (1994) Effect of carotid sinus baroreceptor reflex on hepatic and splenic vascular capacitance in vagotomized dogs. Am J Physiol 266:H1528–33

26. Guyton AC, Polizo D, Armstrong GG (1954) Mean circulatory filling pressure measured immediately after cessation of heart pumping. Am J Physiol 179:261–7

27. Shiotani S, Kohno M, Ohashi N et al (2003) Dilatation of the heart on postmortem computed tomography (PMCT): comparison with live CT. Radiat Med 21:29–35

28. Levy AD, Harcke HT, Mallak CT (2010) Postmortem imaging: MDCT features of postmortem change and decomposition. Am J Forensic Med Pathol 31:12–7. doi:10.1097/PAF.0b013e3181c65e1a

29. Zech WD, Jackowski C, Buetikofer Y, Kara L (2014) Characterization and differentiation of body fluids, putrefaction fluid, and blood using Hounsfield unit in postmortem CT. Int J Legal Med 128:795–802. doi:10.1007/s00414-014-1030-0

30. Mull RT (1984) Mass estimates by computed tomography: physical density from CT numbers. AJR Am J Roentgenol 143:1101–4. doi:10.2214/ajr.143.5.1101

31. Azevedo-Alanis LR, Tolentino Ede S, Assis GF, Cestari TM, Lara VS, Damante JH (2015) Acinar autolysis and mucous extravasation in human sublingual glands: a microscopic postmortem study. J Appl Oral Sci Revista FOB 23:459–66. doi:10.1590/1678-775720150139

32. Gmaz-Nikulin E, Nikulin A, Plamenac P, Hegewald G, Gaon D (1981) Pancreatic lesions in shock and their significance. J Pathol 135:223–36

33. Hyun JJ, Chun HJ, Keum B et al (2012) Autolysis: a plausible finding suggestive of long ESD procedure time. Surg Laparos Endosc Percutan Tech 22:e115–7. doi:10.1097/SLE.0b013e318247c347

34. Bell H, Rostad B, Raknerud N, Try K (1994) Computer tomography in the detection of hemochromatosis. Tidsskr Nor Laegeforen 114:1697–9

35. Amirbekian S, Ibrahim SM, Shin MS (2013) Incidental hyperdensities within the reticuloendothelial system. Clin Imaging 37:583–5. doi:10.1016/j.clinimag.2012.09.001

36. Miyajima J, Okajima S, Takao H, Nakashima A, Hombo Z (1985) Estimation of thorium deposited in Thorotrast patients by CT scanner in comparison with whole body counter. J Radiat Res 26:196–210

37. Levi C, Gray JE, McCullough EC, Hattery RR (1982) The unreliability of CT numbers as absolute values. AJR Am J Roentgenol 139:443–7. doi:10.2214/ajr.139.3.443

38. Groell R, Rienmueller R, Schaffler GJ, Portugaller HR, Graif E, Willfurth P (2000) CT number variations due to different image acquisition and reconstruction parameters: a thorax phantom study. Comput Med Imaging Graph 24:53–8

39. Nishihara S, Koike M, Ueda K, Sanada T, Ebitani K (2002) Intra- and inter-equipment variations in the mean CT numbers of a vertebral body for X-ray CT equipment. Med Imaging Inf Sci 20:40–3

40. Jackowski C, Sonnenschein M, Thali MJ et al (2007) Intrahepatic gas at postmortem computed tomography: forensic experience as a potential guide for in vivo trauma imaging. J Trauma 62:979–88. doi:10.1097/01.ta.0000198733.22654.de

41. Singh MK, O'Donnell C, Woodford NW (2009) Progressive gas formation in a deceased person during mortuary storage demonstrated on computed tomography. Forensic Sci Med Pathol 5:236–42. doi:10.1007/s12024-009-9103-y