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ORIGINAL ARTICLE

Postmortem volume change of the spleen and kidney on early postmortem computed tomography: comparison with antemortem computed tomography

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Abstract

Purpose To clarify an early postmortem change, we investigated the volume changes of the spleen and kidney on postmortem CT compared with antemortem CT in the same patients.

Materials and methods We retrospectively evaluated the volumes of 56 spleens (56 cases) and 50 kidneys (25 cases) using antemortem and postmortem CT, which were performed within 168 min after death. We divided the cases of spleen analysis into a hemorrhagic group ($n=12$) and a non-hemorrhagic group ($n=44$).

Results The volumes of the organs before and after death were 101.0 ± 70.9 (cm^3, mean ± standard deviation) and 81.1 ± 57.8 in spleens, 120.3 ± 49.2 and 109.2 ± 39.2 in kidneys, respectively. Both spleens and kidneys shrank after death ($p<0.05$). The volumes of spleens before and after death were 111 ± 66.5 and 67.5 ± 27.7 in the hemorrhagic group, and 98.2 ± 72.5 and 84.9 ± 63.3 in the non-hemorrhagic group, respectively. The median value of the ratio of postmortem splenic volume to antemortem volume in the hemorrhagic group (65.0%) was smaller than the one in the non-hemorrhagic group (90.5%) ($p<0.05$).

Conclusion We demonstrated that spleens and kidneys significantly reduced in size after death. The rate of shrinkage of spleens in the hemorrhagic group significantly became larger than the one in the non-hemorrhagic group.

Keywords Postmortem changes · Postmortem computed tomography · Spleen · Kidney

Abbreviations

PMI	Postmortem imaging
CT	Computed tomography
MRI	Magnetic resonance imaging
PMCT	Postmortem CT
AMCT	Antemortem CT
P/A ratio	The ratio of postmortem volume to antemortem volume
MDCT	Multidetector CT
ROI	Region of interests

Introduction

Postmortem imaging (PMI) using modern imaging technologies, such as multi-detector computed tomography (CT) or magnetic resonance imaging (MRI), has been introduced to forensic medicine for these 2 decades [1–4]. Since traditional autopsy rates declined recently, PMI is considered as a reliable cause of death diagnostic process and is a different modality from a traditional autopsy. Though MRI has a fine tissue contrast, it has limited access and needs long examination time. Therefore, CT is more commonly performed for postmortem examination. Postmortem CT (PMCT) is able to depict some conditions, e.g., fractures, gas or fluid in body cavities, and foreign bodies, and is useful to diagnose some hemorrhages, inflammations, or injuries [5–7]. However, PMCT is not the same as clinical imaging. There are some different findings, postmortem changes and changes due to cardiopulmonary resuscitations on PMCT. It is important to understand postmortem features for interpreting PMCT [8–10].

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Postmortem changes, e.g., livor mortis, rigor mortis algor mortis, and decompression, have been evaluated by autopsy to date, however, they are observed only on corpses. On the other hand, findings on PMI are able to be compared with ones on antemortem imaging in the same patient. Some investigators have reported dynamic changes from the antemortem to postmortem state by comparing images before and after death. Blood sedimentation, loss of grey–white matter differentiation, hyperdense aortic wall, change of aortic shape, and cardiac wall thickening have been revealed by comparing postmortem with antemortem CT (AMCT) [11–15].

PMCT is also useful for determining organ volume [16]. In this our study, we investigated the volume changes of the spleen and kidney on PMCT compared with AMCT in the same patients. We also evaluated the organ volume change affected by infusion. The aim of this study is to clarify an early postmortem volume change of spleens and kidneys.

Materials and methods

Patients

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This retrospective study was approved by the review board of our hospital (approval number 15-004) and the need for obtaining informed consent was waived. Between January 2008 and December 2014, 1691 postmortem torso CT scans were performed in our hospital. We selected 65 patients that underwent abdominal CT within 78 days before death.

Spleens

We evaluated 56 cases (56 spleens) for spleen analysis with nine excluded cases (three cases that underwent splenectomy, four cases in which spleens were not scanned, and two cases with artifact) (Fig. 1). Ages and sexes of the cases were 34–92 years (mean 75 years) and included 35 males. The causes of death were classified as 56 non-traumatic cases and 2 traumatic cases (Table 1). Traditional autopsies were performed in nine non-traumatic cases. The autopsies showed no pathological findings in the spleens. The causes of death in the rest of the non-traumatic cases were determined on the basis of available clinical information by a board-certified forensic pathologist and a board-certified radiologist with 15 years of experience in postmortem radiology by common consent. We divided the cases into a hemorrhagic group ($n = 12$) and a non-hemorrhagic group ($n = 44$), because it had been reported that spleens shrank in cases with hypovolemic shock [19, 20]. One case with subarachnoid hemorrhage was classified as a non-hemorrhage group because the volume of bleeding was not large. We also evaluated the volume of infusion in cardiopulmonary resuscitation, and divided the cases into

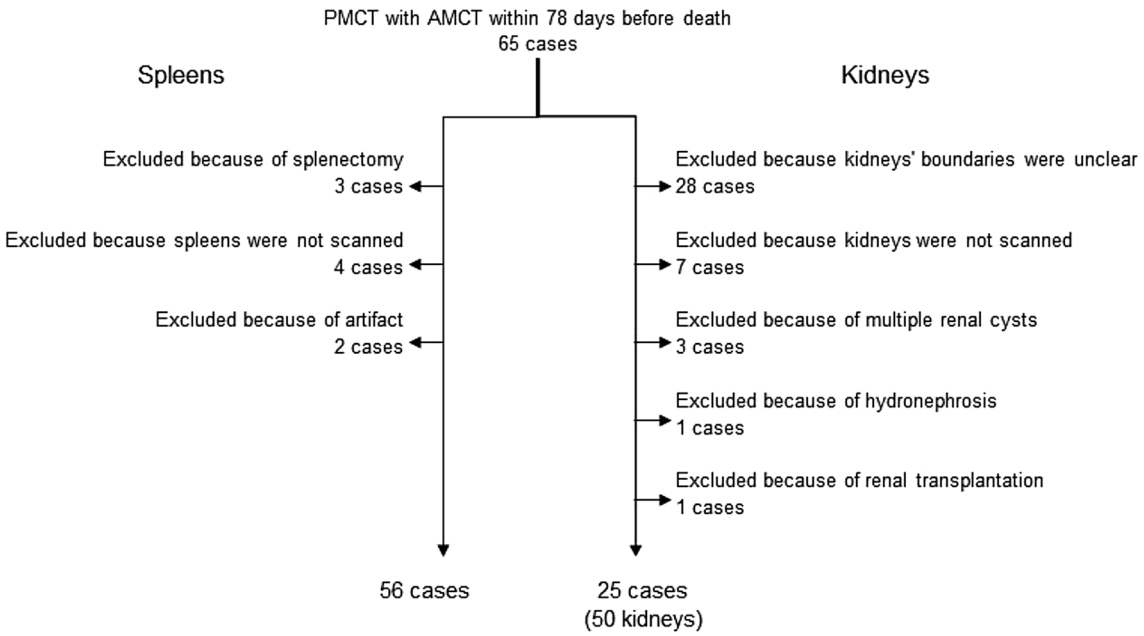

Fig. 1 Flow diagram of selected cases. *PMCT* postmortem CT, *AMCT* antemortem CT

Table 1 Causes of death

	Spleen	Kidney
Hemorrhagic group		
Intestinal hemorrhages[a]	4	2
Aortic dissection ruptures	3	
Aortic aneurysm ruptures	3	
Multiple traumas	2	
Non-hemorrhagic group		
Inflammatory diseases[b]	6	3
Malignant neoplasms[c]	3	
Digestive system diseases[d]	3	3
Cardiac diseases[e]	4	3
Chronic renal failure	2	
Pneumothorax	1	
Respiratory failure	1	
Suffocation	1	
Subarachnoid hemorrhage	1	
Unknown[f]	22	14
Total	56	25

Causes of death were determined by traditional autopsies in nine cases

[a]1 case (esophageal cancer invasion to common carotid artery)

[b]1 case (pneumonia)

[c]2 cases (gastric carcinoma and renal cell carcinoma)

[d]2 cases (non-obstructive mesenteric ischemia and ischemic gastroenteritis)

[e]2 cases (acute cardiac infarction and cardiac amyloidosis)

[f]1 case (unknown)

three groups (none: $n=15$, under 500 ml: $n=36$, and over 500 ml: $n=5$).

Kidneys

We evaluated 25 cases (50 kidneys) for renal analysis with 40 excluded cases (28 cases with the kidneys' boundaries were unclear, 7 cases in which kidneys were not scanned, 3 cases with multiple renal cysts, 1 case with hydronephrosis, and 1 case that underwent renal transplantation) (Fig. 1). Ages and sexes of the cases were 34–92 years (mean 73 years) and included 13 males. All cases were non-traumatic deaths. Traditional autopsies were performed in six cases, and showed no pathological findings in the kidneys except for renal cysts or small renal stones. The details of the causes of death are summarized in Table 1. There were only two hemorrhagic cases; therefore, we did not divide the cases into a hemorrhagic group and a non-hemorrhagic group. Infusion therapies immediately before death were performed in 19 cases (38 kidneys). Because there was only one case who had received infusion over 500 ml, we divided the cases into a non-infusion group ($n=12$) and an infusion group ($n=38$).

CT examination

Antemortem CT

AMCT examinations were performed 0–78 days (median 22 days) in spleen cases, and 0–66 days (median 18 days) in kidney cases before death. The examinations were performed by three MDCT units; a 16-row detector MDCT (SOMATOM Sensation 16; Siemens Healthcare, Erlagen, Germany) and two 64-row detector MDCT (SOMATOM Sensation 64, and SOMATOM Definition; Siemens Healthcare, Erlagen, Germany) except for one case which underwent CT in another hospital. We evaluated non-contrast CT except for 21 spleen cases that underwent only contrast-enhanced CT. Therefore, we used 35 non-contrast CT and 21 contrast-enhanced CT in spleen cases, and 25 non-contrast CT in renal cases.

Postmortem CT

The periods between determinations of death and PMCT examinations ranged from 5 to 168 min (median 27 min) in the spleen cases, and from 11 to 168 min (median 40 min) in kidney cases. PMCT examinations were performed with two MDCT units; a 16-row detector MDCT (SOMATOM Sensation 16; Siemens Healthcare, Erlangen, Germany) and a 64-row detector MDCT (SOMATOM Definition AS; Siemens Healthcare, Erlangen, Germany). Spiral mode imaging was performed from the skull vertex to the knee. Examinations were performed in the natural supine position with the patients' arms at their sides. No contrast material was administered.

CT technique

The following axial spiral data were obtained: 0.6 mm collimation, 11.5 mm feed/rotation, 0.6 pitch factor, and 1.5 mm collimation; 18 mm feed/rotation, 0.75 pitch factor with 64-row and 16-row detector MDCT scanners, respectively. Axial images were reconstructed with a 350 mm FOV and a 512×512 imaging matrix and 2 mm section thicknesses in both postmortem and antemortem examinations except for one case that underwent AMCT in another hospital. Axial images with 5 mm section thickness were evaluated in the case.

Volume analysis

Volumes of the spleens and the kidneys on AMCT and PMCT were obtained for analysis. Organs volumes were measured with an image processing program on a multi-paradigm numerical computing environment and programming language (MATLAB R2014a; MathWorks, Natick MA, US)

[16]. The images were evaluated by two operators among five medical students, who received specific training by an experienced board-certified radiologist in identification of spleens or kidneys, for each case. The operators set regions of interests (ROIs) on the images. The volumes of the organs were calculated by multiplying the ROIs and slice thickness and adding all of them (Figs. 2 and 3). The ROIs set by the operators were confirmed by the radiologist. Average values of volumes measured by the two operators were used for analysis. We calculated the ratio of postmortem volume to antemortem volume (*P/A* ratio) of each group.

Statistical analysis

Statistical analysis was preformed using R 2.8.1 (R Development Core Team, Auckland, New Zealand). To confirm the difference between the spleen volumes on non-contrast CT and ones on contrast CT, Wilcoxon signed-rank test was used. We also used Wilcoxon signed-rank test for the relations between the volume changes on AMCT and PMCT in splenic analysis except for the correlation between the volume changes in the over 500 ml infusion group. Because it did not have enough cases ($n=5$), Paired *t* test was used after confirming that it followed the normal distribution with Kolmogorov–Smirnov test. We used Mann–Whitney's *U* test and Kruskal–Wallis test to examine the relations in the *P/A* ratio between hemorrhagic and non-hemorrhagic groups and among three infusion groups in splenic analysis, respectively.

Wilcoxon signed-rank test was used for the relations between the volume changes on AMCT and PMCT in kidney analysis. We used Mann–Whitney's *U* for the relations between the *P/A* ratios of no infusion group and infusion group in renal analysis.

A p value of less than 0.05 was considered to indicate a statistically significant difference.

Results

The volumes of spleen on AMCT with and without contrast enhancement were 96.9 ± 76.6 cm^3 and 103.5 ± 68.3 cm^3 (mean ± standard deviation), respectively.

The volumes of spleen and kidney before and after death were summarized in Table 2.

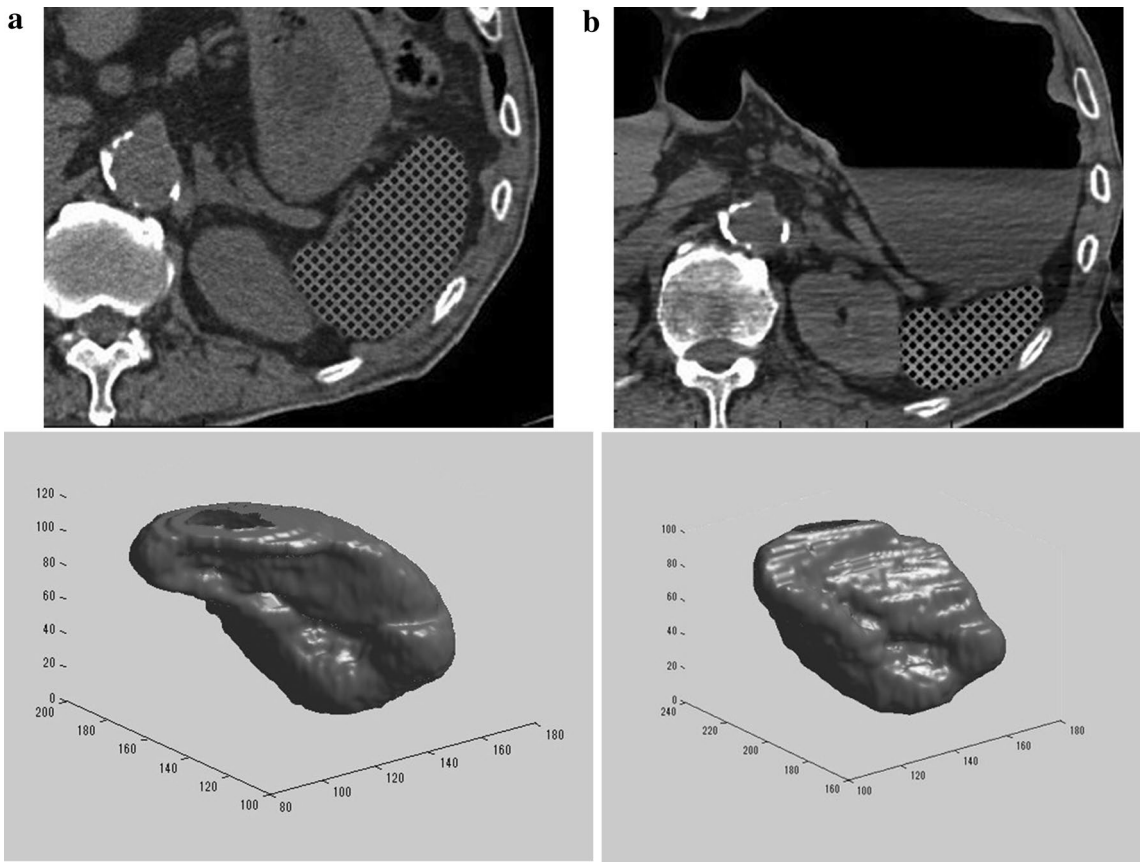

Fig. 2 79-year-old male, who died from hematemesis. Splenic volume measurements and three-dimensional images on antemortem CT (**a**) and postmortem CT (**b**). The volumes of the spleen on antemortem and postmortem CT were 242.4 cm^3 and 112.1 cm^3, respectively

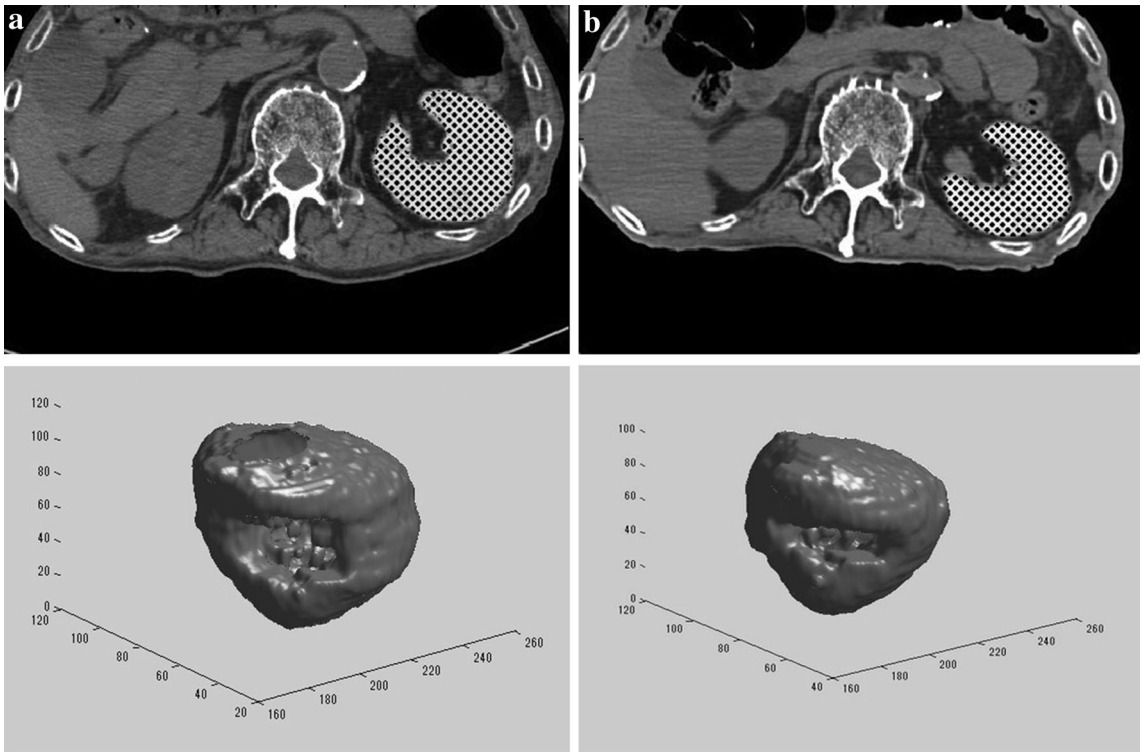

Fig. 3 76-year-old male, who died from cardiac failure. Left renal volume measurements and three-dimensional images on antemortem CT (**a**) and postmortem CT (**b**). The volumes of the kidney on antemortem and postmortem were 214.8 cm^3 and 133.7 cm^3, respectively

Table 2 The volume of organs before and after death

	Antemortem (cm^3)	Postmortem (cm^3)	
Spleen ($n=56$)	101.0 ± 70.9	81.1 ± 57.8	$p<0.05$*
Hemorrhagic/non-hemorrhagic			
Hemorrhagic group ($n=12$)	111.4 ± 66.5	67.5 ± 27.7	$p<0.05$*
Non-hemorrhagic group ($n=44$)	98.2 ± 72.5	84.9 ± 63.3	$p<0.05$*
Infusion			
Non-infusion ($n=15$)	87.2 ± 62.2	61.8 ± 36.9	$p<0.05$*
Under 500 ml ($n=36$)	109.0 ± 77.7	90.0 ± 64.8	$p<0.05$*
Over 500 ml ($n=5$)	84.8 ± 33.4	75.6 ± 46.6	n.s**
kidney ($n=50$)	120.3 ± 49.2	109.2 ± 39.2	$p<0.05$*
Infusion			
(−) ($n=12$)	102.9 ± 68.1	83.9 ± 39.7	n.s*
(+) ($n=38$)	125.8 ± 41.1	117.2 ± 36.0	$p<0.05$*

Mean ± standard deviation

n.s non-significant

*Wilcoxon signed-rank test

**Paired *t* test

Spleens

There were no statistically significant differences between them ($p=0.1924$). The volume of spleen decreased after death ($p<0.05$). The spleen shrank after death in the hemorrhagic group, the non-hemorrhagic group, the non-infusion group, and the under 500 ml infusion group ($p<0.05$). Though the volume of spleen decreased after death in over 500 ml infusion group, there was no statistically significant difference between on AMCT and on PMCT ($p=0.579$). The volumes decreased in 11 of 12 cases in the hemorrhagic group and 32 of 46 cases in the

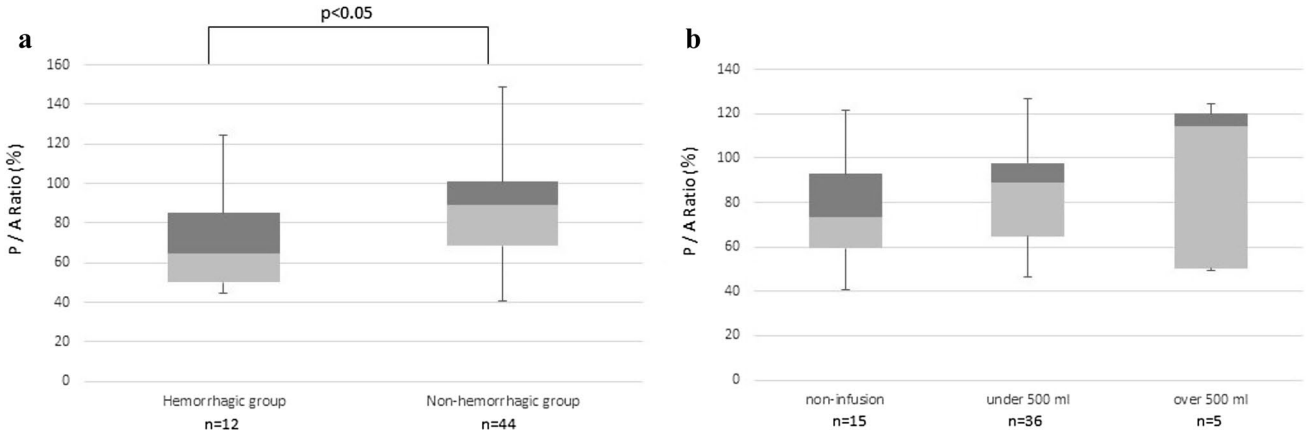

Fig. 4 **a** Ratio of postmortem spleen volume to antemortem spleen volume. The median values of the *P/A* ratio were 65.0% in the hemorrhagic group, and 89.2% in the non-hemorrhagic group. The ratio in the hemorrhagic group was significantly smaller than in the non-hemorrhagic group. The Mann–Whitney's *U* test was used. **b** Ratio of postmortem spleen volume to antemortem spleen volume of cases among three infusion groups. There were no statistically significant differences among each groups. The median values of the *P/A* ratio were 73.6%, 87.8%, and 114.5% in the non-infusion group, the under 500 ml group, and the over 500 ml group, respectively. The Kruskal–Wallis test was used

non-hemorrhagic group after death. The mean values of the *P/A* ratio were 71.4% in the hemorrhagic group and 87.3% in the non-hemorrhagic group. The rate of volume changes in the hemorrhagic group was larger than one in the non-hemorrhagic group ($p < 0.05$) (Fig. 4a). The mean values of the *P/A* ratio were 76.0%, 86.0%, and 91.8% in the non-infusion group, the under 500 ml group, and the over 500 ml group, respectively. The volumes increased in 3 of 5 cases in the over 500 ml infusion group. Though the averages of the P/A ratio were higher in the infusion groups, there were no statistically significant differences among them ($p = 0.3755$) (Fig. 4b).

Kidneys

The kidney shrank after death ($p < 0.05$). The volumes statistically decreased in the infusion group ($p < 0.05$), but not in the non-infusion group ($p = 0.0995$) (Table 2). The renal volumes decreased in 35 of 50 kidneys after death. Both kidneys shrank in 15 cases and distended in 5 cases. Unilateral kidneys shrank in five cases. The mean value of the *P/A* ratio was 89.9% in the non-infusion group and 94.5% the in infusion group. There were no statistically significant differences in the P/A ratio between the non-infusion group and the infusion group ($p = 0.6826$) (Fig. 5).

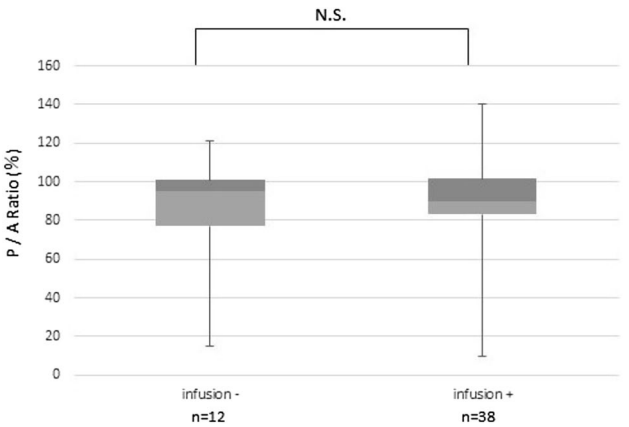

Fig. 5 Ratio of postmortem renal volume to antemortem renal volume. The median value of the *P/A* ratio was 94.8% in the non-infusion group and 90.1% in the infusion group. There was no statistically significant difference between both groups. The Mann–Whitney's *U* test was used

Discussion

Postmortem organic volume changes have been reported in adrenal grands and spleens by means of comparing PMCT with AMCT [17, 18]. Ishida et al. reported the adrenal glands shrank after death, and the mean reduction rates of the right and left adrenal glands were 32% and 24%, respectively. They discussed that lipid depletion due to acute stress might have reduced the volume of the adrenal glands in agonal states [17]. Okuma et al. reported that the spleen decreased in volume on PMCT compared with AMCT, and the rates of the volume change were 80%, 95%, and 70% in the normal group, splenic infarct group and splenic tumor-infiltration group, respectively. They mentioned that the postmortem changes in spleen volume were not significantly associated with sex, age, time elapsed since death, or cause of death. The reduction

of volume of the spleen after death might have been due to hypovolemic or distributive shock of agonal state [18].

In this study, spleens and kidneys significantly reduced in size after death. We considered the contraction of organs might have been associated with the decreasing blood volume due to cessation of blood and activation of the sympathetic nerve system at the agonal state. First, the cessation of blood flow results in circulatory pressure dropping approximately 7 mmHg [21]. Since a large quantity of blood in the body is stored in the venous system [22], the amount of blood in organs decreases. Secondly, stimulation of the sympathetic nerves causes a reduction of volume of organs. It is well known that the spleen shrinks in association with sympathetic nervous system activity in humans [19, 20, 23–25]. On the other hand, the physical contraction of kidneys is not known. However; stimulation of the renal sympathetic nerves causes a reduction of renal blood flow [26]. The blood volume of spleens and kidneys may decrease according to these functions after death. Interestingly enough, the volume changes of spleens in the non-hemorrhagic group were the same as that of kidneys in this our study.

The spleen in the hemorrhagic group significantly became smaller than the one in the non-hemorrhagic group in our study. Our results differed from a previous study, as the cause of death did not affect the volume change of spleen, reported by Okuma et al. [18]. Kiguchi et al. reported that the volume of the spleen was reduced during hypovolemic shock and rapidly increased after treatment. They considered that the shrinkage of spleens was associated with not only the functions mentioned above but also its blood cell storage function. The blood in the spleen flows out in a hypovolemic shock state, hence the volume of the spleen decreases [19]. Okuma et al. treated cases that died from non-hemorrhagic diseases in hospital death. We consider that the blood volume is related to the reduction of the splenic volume. Keeping in mind this phenomenon, it may be possible to diagnose corpses with marked small spleens as hemorrhagic deaths.

Though kidney decrease in size in 70% of cases, 30% (15 of 50, 10 bilateral kidneys, 5 unilateral kidneys) of the kidneys increase in size after death. The unilateral renal enlargement may be associated with postmortem hypostasis. Cessation of circulation and the relaxation of the muscular tone of the vascular bed allows simple fluid movement to occur within the blood vessels [27]. The enlargement of the organs might have been associated with the body posture after death. However, we could not investigate the body posture according to the information contained in the documents in this retrospective study.

Our study has some limitations. First, we were able to treat only a small sample size of subjects. However, we were able to obtain antemortem information of patients who visited the hospital and evaluate not only PMCT but also AMCT. They must be valuable data which are hardly obtained in forensic institutions. Second, there are limitations due to the retrospective study. The descriptions in the medical documents of the situation of death were limited. Postmortem changes are modified according to the situations of deaths, e.g., the body postures, temperatures, and so on. However, there were not enough descriptions about the situations surrounding deaths in many cases. Third, the situations of the patients at AMCT were not well known in many cases. Since the examinations should have been performed when the patients exhibited pathological conditions, the volume of organs might have changed according to various circumstances. Furthermore, our study did not present enough pathological evidence. The autopsies were performed in only nine cases in the spleen and four kidney cases, respectively. In the remaining cases, the causes of death were determined using the clinical information. The organ volume may be affected by causes of death.

Conclusion

We demonstrated that spleen and kidney significantly reduced in size after death. It was thought that the contractions of spleen and kidney were associated with the cessation of blood and activation of the sympathetic nerve system at the agonal state. The spleen in the hemorrhagic group significantly became smaller than the one in the non-hemorrhagic group in this our study. The mean ratios of postmortem volume to antemortem volume in spleen and kidney tended to be higher in infusion groups. The volume change of spleen and kidney after death may be affected by infusion during cardiopulmonary resuscitation.

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Compliance with ethical standards

Conflict of interest Naoya Takahashi declares that he has no conflict of interest. Keisuke Yajima declares that he has no conflict of interest. Madoka Otaki declares that she has no conflict of interest. Yurina Yoshikawa declares that she has no conflict of interest. Ayumi Ishihara declares that she has no conflict of interest. Yuki Sato declares that she has no conflict of interest. Takeshi Higuchi declares that he has no conflict of interest. Hisakazu Takatsuka declares that he has no conflict of interest.

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