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ORIGINAL ARTICLE

Postmortem computed tomography for detecting causes of sudden death in infants and children: retrospective review of cases

Yuji Oyake · Takeshi Aoki · Seiji Shiotani
Mototsugu Kohno · Noriyoshi Ohashi
Hiroyoshi Akutsu · Kentaro Yamazaki

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Abstract
Purpose. The aim of this study was to investigate the usefulness of postmortem computed tomography (PMCT) in detecting causes of sudden death in infants and children.
Materials and methods. Our subjects were 15 nontraumatically deceased patients (nine boys and six girls, ranging in age from 20 days after birth to 12 years old, mean age 1.6 years), who had been in a state of cardiopulmonary arrest on arrival at our hospital. PMCT was performed within 2 h after certification of death: head (15 cases), chest (11 cases), and abdomen (12 cases). Blood was collected from 11 of the patients at the time of cardiopulmonary resuscitation. An autopsy was conducted on two.
Results. PMCT did not show any traumatic changes indicating child abuse. It was difficult to presume the cause of death with PMCT alone, but the cause of death in 14 of 15 cases could be presumed by combining information from their medical history, clinical course before death, PMCT findings, laboratory data, and bacterial culture. The remaining subject was classified as cause unknown.
Conclusion. The causes of sudden death in infants and children were detected at a high rate when we comprehensively investigated the PMCT and other examination findings.

Key words Postmortem computed tomography (PMCT) · Autopsy imaging · Sudden infant death · Forensic radiology

Y. Oyake (✉)
Department of Pediatrics, Oyake Children's Clinic, 3-7-19 Higashiishikawa, Hitachinaka 312-0052, Japan
Tel. +81-29-273-7182; Fax +81-29-272-4227
e-mail: y-oyake@dc4.so-net.ne.jp

T. Aoki
Department of Pediatrics, Tsukuba Medical Center, Tsukuba, Japan

S. Shiotani
Department of Radiology, Tsukuba Medical Center, Tsukuba, Japan

M. Kohno · N. Ohashi
Department of Critical Care and Emergency Medicine, Tsukuba Medical Center, Tsukuba, Japan

H. Akutsu
Department of Neurosurgery, Tsukuba Medical Center, Tsukuba, Japan

K. Yamazaki
Department of Forensic Medicine, Tsukuba Medical Examiner's Office, Tsukuba, Japan

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Introduction

In Japan, the diffusion of the medical examiner system is insufficient and permission to perform a nonjudicial autopsy is often denied by the family, mostly for emotional reasons. In recent years, as an alternative to or a concomitant method with autopsy, new concepts of virtual autopsy[1] and autopsy imaging[2] have been proposed using imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI). Several researchers have reported postmortem imaging using MRI to investigate perinatal deaths and pediatric deaths.[3–9] However, there have been only a few reports

Table 1. overall findings of sudden infant death cases

Case	Age	Sex	Preexisting disease	Signs and symptoms	Laboratory data	PMCT findings: Brain
1	1 m	F	Turner syndrome	None	WBC 18,800 CRP 0.0	Intravascular gas
2	2 y	F	Tetralogy of Fallot (shunt operation)	None	WBC 17,700 CRP 0.2	Unremarkable
3	12 y	M	Tetralogy of Fallot (treated)	None	WBC 6,000 CRP 0.0	Unremarkable
4	4 y	M	Congenital adrenal hypoplasia	None	Not performed	Brain atrophy
5	11 m	F	Congenital cytomegalovirus infection	Cough Rhinorrhea	WBC 11,800 CRP 0.4	Ventricular dilatation
6	5 m	M	Vesicoureteral reflux or ureterovesical junction obstruction	Vomiting	WBC 10,400 CRP 6.3	Brain edema
7	2 y	M	None	Vomiting Abdominal pain	WBC 25,500 CRP 0.2	Unremarkable
8	21 d	M	Intrauterine growth retardation (IUGR)	Fever Nasal obstruction	Not performed	Brain edema
9	1 y	M	None	None	Not performed	Unremarkable
10	8 m	F	None	Fever Vomiting	Not performed	Unremarkable
11	1 m	F	None	None	WBC 13,200 CRP 0.1	Brain edema
12	2 m	M	None	None	WBC 18,100 CRP 0.3	Brain edema
13	1 m	M	None	Cough Rhinorrhea	WBC 11,200 CRP 0.0	Unremarkable
14	1 m	F	Intrauterine growth retardation (IUGR)	Nasal obstruction	WBC 14,200 CRP 0.0	Unremarkable
15	5 m	M	None	None	WBC 3,600	Unremarkable

d, *x*-day-old; m: *x*-month-old; y, *x*-year-old; M, male, F, female; WBC, white blood cell count; RA, right atrium; CVG, cardiovascular gas; CRP, C-reactive protein; RV, right ventricle; HPVG, hepatic portal venous gas; GI, gastrointestinal; LV, left ventricle; SIDS, sudden infant death syndrome

on pediatric postmortem computed tomography (PMCT) findings.[10,11] We have been conducting PMCT in our institution since 1985 to detect the cause of death in patients who were in cardiopulmonary arrest on arrival (CPAOA) and as a screening method to investigate the necessity of a subsequent classic autopsy.[12]

In this study, we evaluated the usefulness of PMCT to detect the causes of sudden death in infants and children by combining PMCT findings with other examination results. We believe that this is the first published report on pediatric whole-body PMCT with the findings of multiple cases.

Materials and methods

Our subjects were 15 deceased subjects who arrived in our emergency room (ER) in a state of CPAOA between January 1993 and December 2002. They were examined by CT within 2 h after certification of death. The group included nine boys and six girls ranging in age from 20 days after birth to 12 years (mean age 1.6 years). Preexisting diseases were intrauterine growth retardation (IUGR) in two cases, tetralogy of Fallot (TOF) in two cases, Turner's syndrome in one case, congenital cytomegalovirus infection in one case, and a complication of adrenal hypoplasia and myopathy in one case (Table 1).

All patients underwent cardiopulmonary resuscitation (CPR): artificial respiration with bag-valve masking, and tracheal intubation, cardiac massage, and infusion. The radiographic skeletal survey[13] was not done, as child abuse was not suspected based on pediatricians' examinations, including an ophthalmoscopic examination, inquiries to the parents, and inquests by police. PMCT (CT, Accel Proceed; GE Medical

Chest	Abdomen	Chest Xray	Autopsy	Final diagnosis
Increased attenuation (6/6) CVG (RA, RV, LV) endotracheal air defect	HPVG	Opaque thorax	Performed	Pneumonia + congestive heart failure
Increased attenuation (4/6)	Unremarkable	Cardiomegaly	Not performed	Anoxic spell
Not performed	Not performed	Cardiomegaly	Not performed	Sudden cardiac death
Not performed	Distension of the right hemicolon	Right upper lobe atelectasis	Not performed	Adrenal hypoplasia (preexisting disease)
Increased attenuation (4/6) CVG (LV)	GI distention	Blurring of the right side	Not performed	Pneumonia
Increased attenuation (5/6)	Hydronephrosis GI distention	Opaque left hemithorax	Not performed	Urosepsis
Increased attenuation (6/6)	Ileus GI distention and HPVG	Unremarkable	Not performed	Hypovolemic shock due to dehydration
Not performed	Not performed	Opaque thorax	Performed	Pneumonia
Increased attenuation (6/6) CVG (RA) endotracheal air defect	Unremarkable	Opaque thorax	Not performed	Pneumonia
Not performed	Not performed	Opaque thorax Endotracheal air defect	Not performed	Pneumonia
Increased attenuation (6/6)	Unremarkable	Opaque left hemithorax	Not performed	Pneumonia
Increased attenuation (6/6)	Unremarkable	Not performed	Not performed	Pneumonia
Increased attenuation (6/6) endotracheal air defect	GI distention	Hazy increase in opacity of bilateral lungs	Not performed	Pneumonia
Increased attenuation (6/6)	Unremarkable	Opaque right upper lobe and left hemithorax	Not performed	Pneumonia
Increased attenuation (1/6) CVG (RA, RV)	Unremarkable	Unremarkable	Not performed	Unknown

Systems, Milwaukee, WI, USA) was performed on the head (15 cases), chest (11 cases), and abdomen (12 cases). The head was scanned at 0.5-cm intervals with 0.5 cm collimation from the orbitomeatal line to the pentagon level and in the upper area by 1.0-cm intervals with 1.0 cm collimation. The chest and abdomen were scanned by 1.0-cm intervals with 1.0 cm collimation. Each region was observed at the appropriate window level and window width setting. A chest radiograph had been obtained in 14 cases immediately after their arrival in the ER.

Two experienced pediatricians and one board-certified diagnostic radiologist retrospectively reviewed the PMCT scans of the brain, chest, and abdomen and judged whether the following evaluation items were positive or negative by means of consensus. Other abnormal findings were also recorded if present.

- *Brain.* Brain edema was diagnosed positive when the basal ganglia and thalamus were poorly visible or not visible.[14]
- *Chest.* Increased lung parenchymal attenuation was defined when there was either "ground-glass attenuation" (a hazy increase in the lung parenchymal attenuation not associated with obscuration of underlying vessels[15]) or "consolidation" (homogeneous increase in the lung parenchymal attenuation attributed to the obscuration of underlying vessels[15]). The right lung was segmented into three regions (upper, middle, and lower lobes); and the left lung was segmented into three regions (upper, lingual, and lower lobes). Then the presence of increased attenuation was evaluated in these six lung regions, scoring 1 when the attenuation was increased in each segment (range 0–6). "Dependent density" (subpleural increased attenuation in the dependent lung[15]) was not counted.

- *Abdomen.* Gastrointestinal (GI) distention was diagnosed positive when excessive air (beyond the ordinary physiological amount) is retained in the enteric canal. Because the body of a child is smaller than that of an adult, the same GI distension diagnostic category[16] cannot be applied. Therefore, GI distention in our study was defined as positive when the maximum diameter of the body of the stomach was measured to be more than one-half the transverse diameter of the body on a chest radiograph or on PMCT.

Blood was collected from 11 subjects at the time of CPR. As indices for inflammation, the white blood cell (WBC) count and C-reactive protein (CRP) were examined. As for the WBC count, leukocytosis was diagnosed when elevated to 12000/μl or higher in infants <6 months old, and 10000/μl or higher in infants ≥6 months old. The neutrophil count and shift to the left were not evaluated because of the nature of the emergent examination. Regarding CRP, significant elevation was defined as ≥0.5 mg/μl. Other biochemical postmortem changes in the blood[17,18] were not considered.

Although autopsy was recommended to the family of each patient, consent to perform the autopsy was obtained from only 2 of the 15 families.

Results

The overall findings of the 15 infants and children are summarized in Table 1. None of them showed any traumatic changes on PMCT, such as intracranial (subarachnoid, subdural, intraventricular) hemorrhage,[19] or rib fractures,[20] which are indicative of child abuse.

Among the 15 brain CTs, 4 revealed brain edema, which was poorly visible in the basal ganglia and thalamus. Other brain CT findings were intravascular gas in one case, brain atrophy in one case, and ventricular dilatation in one case.

Chest CT scans of 11 subjects showed increased attenuation of the lung parenchyma, although the chest radiograph either underrated these findings or did not show them. The CT showed cardiovascular gas (CVG) in four cases, whereas the chest radiograph did not. Furthermore, chest CT showed an endotracheal or endobronchial air defect (something other than air being present in the trachea or main bronchi) in three cases. The endotracheal air defect was seen on the chest radiograph in one case but not in the other two.

Abdominal CT of 12 subjects showed GI distention in 4 cases, hepatic portal venous gas (HPVG) in 2 cases, marked enteric liquid retention (ileus) in 1 case, and marked hydronephrosis and hydroureter in 1 case.

Causes of death were diagnosed based on a comprehensive understanding of the preexisting disease, signs and symptoms, laboratory data, PMCT findings, and autopsy findings.

Case description

The case identification numbers are keyed to those shown in Table 1.

Case 1

A 1-month-old girl had preexisting Turner's syndrome.[21] She also evidenced symptoms related to heart failure, including tachypnea and failure to thrive. She was found in a state of cardiopulmonary arrest (CPA) in her bed at home before undergoing a more detailed examination to investigate her congenital heart anomaly. Symptoms of flu such as fever, cough, sneezing, or nasal obstruction were not seen. PMCT of the brain showed arterial intravascular gas (Fig. 1a). PMCT of the chest showed increased diffuse lung attenuation in both lungs (Fig. 1b). Furthermore, PMCT of the chest showed cardiovascular gas (CVG) in the right atrium, right ventricle, and left ventricle (Fig. 1c). PMCT of the abdomen showed HPVG (Fig. 1d). The chest radiograph showed an opaque thorax except for the lateral side of the right middle and lower lung fields (Fig. 1e). It also also showed the tip of the endotracheal tube to have extended far into the right lower bronchus; it was immediately repositioned correctly in the trachea. Leukocytosis was also noted, and pneumonia was suspected. Autopsy showed a ventricular septal defect and as well as pulmonary edema and pneumonia associated with heart valve disease. The cause of death was considered to be a complication of congestive heart failure and pneumonia.

Case 2

A 2-year-old girl underwent a shunt operation for TOF and pulmonary atresia. She suddenly entered a state of dyspnea after having cried for a while in the morning. There were no signs or symptoms of flu. PMCT of the chest showed patchy increased attenuation in both lungs that was not recognized on the chest radiograph. Leukocytosis was found together with an elevated red blood cell count of 751×10^4/μl—thought to be polycythemia arising from the failure of radical operation for TOF. Thus, the cause of death was determined to have resulted from an anoxic spell, negating the possibility of pneumonia.

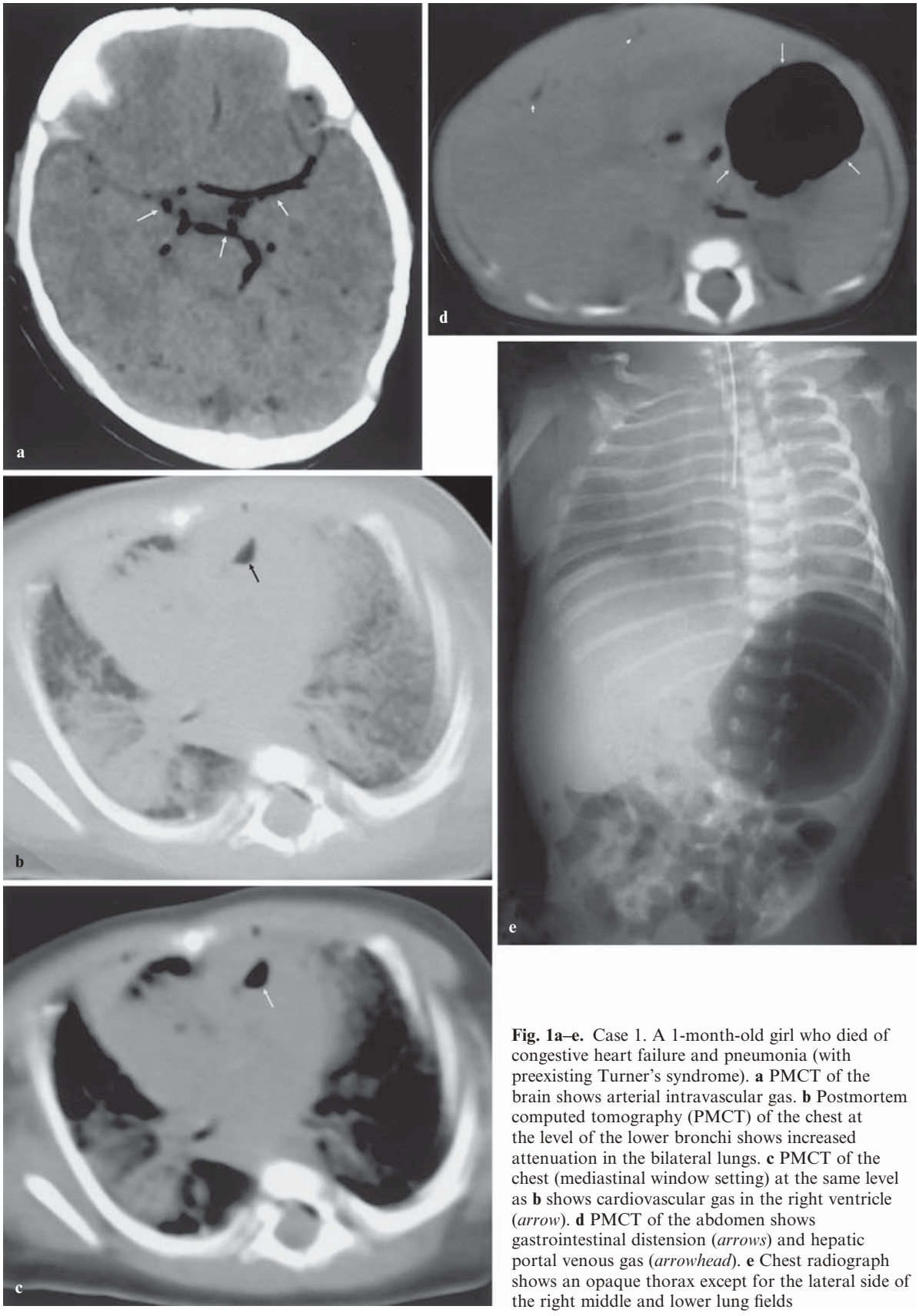

Fig. 1a–e. Case 1. A 1-month-old girl who died of congestive heart failure and pneumonia (with preexisting Turner's syndrome). **a** PMCT of the brain shows arterial intravascular gas. **b** Postmortem computed tomography (PMCT) of the chest at the level of the lower bronchi shows increased attenuation in the bilateral lungs. **c** PMCT of the chest (mediastinal window setting) at the same level as **b** shows cardiovascular gas in the right ventricle (*arrow*). **d** PMCT of the abdomen shows gastrointestinal distension (*arrows*) and hepatic portal venous gas (*arrowhead*). **e** Chest radiograph shows an opaque thorax except for the lateral side of the right middle and lower lung fields

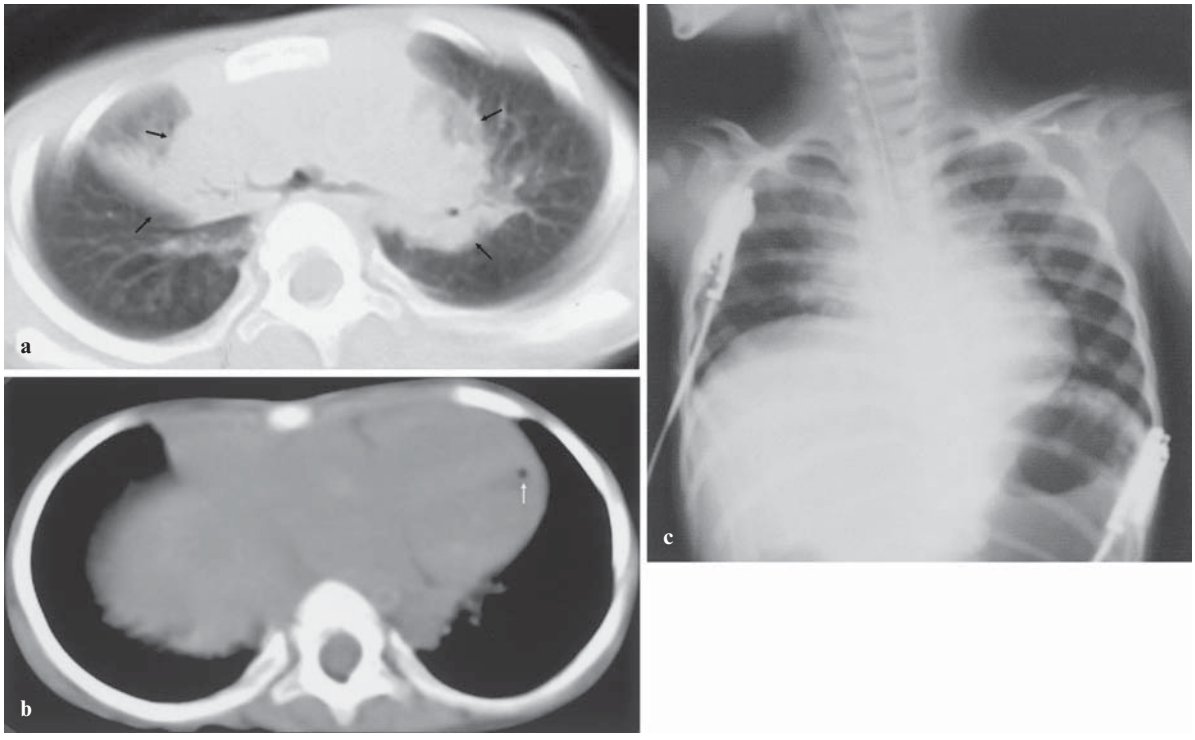

Fig. 2a–c. Case 5. An 11-month-old girl who died of pneumonia (with preexisting congenital cytomegalovirus infection). **a** PMCT of the chest at the level of carina shows increased attenuation on the mediastinal side of both lungs (*arrows*). **b** PMCT of the chest at mediastinal window setting shows cardiovascular gas in the left ventricle (*arrow*). **c** Chest radiograph shows blurring of the right side of the mediastinum

Case 3

A 12-year-old boy after repair of TOF was playing cheerfully but suddenly lay down on the floor, saying he felt sick and entered a state of CPA. The cause of death was considered sudden cardiac death due to arrhythmia.

Case 4

A 4-year-old girl who had a complication of adrenal hypoplasia and myopathy was found in a state of CPA in bed one morning. PMCT of the brain showed diffuse cortical atrophy. The chest radiograph showed right upper lobe atelectasis. Because she had vomited once during the night, right upper atelectasis was thought to be due to aspiration of the vomited matter. PMCT of the abdomen showed dilatation of the right hemicolon, but its pathological significance was not clear. It was also not clear what the right upper lobe atelectasis had to do with her death. Therefore, the cause of death was diagnosed as her preexisting disease adrenal hypoplasia.

Case 5

An 11-month-old girl with congenital cytomegalovirus infection was found in bed by her mother one afternoon in a state of CPA. She had been suffering from a cold and had been coughing since the previous night. She also had a medical history of relatively frequent pneumonia. PMCT of the brain showed ventricular dilatation, which agreed with her antemortem CT findings. PMCT of the chest showed increased lung attenuation on the mediastinal side of both lungs (Fig. 2a) and CVG in the left ventricle (Fig. 2b). The chest radiograph showed only blurring of the right side of the mediastinum (Fig. 2c). PMCT of the abdomen showed GI distention. Laboratory data indicated mild leukocytosis. The cause of death was diagnosed as pneumonia. A culture of arterial blood and sputum in the trachea showed *Haemophilus influenzae*.

Case 6

A 5-month-old boy with episodes of clouded urine (presumably pyuria) twice within a week before his death,

vomited a few times a day for 2 days before he died.[22] On the morning of his death, he had high fever and entered a state of CPA a few hours later. PMCT of the chest showed increased attenuation in the right lower lobe, the lingular segment of the upper lobe, and the lower lobes. A chest radiograph showed an opaque left hemithorax. PMCT of the abdomen showed right-dominant hydronephrosis and hydroureter.

Laboratory data showed leukocytosis and elevated CRP. It appears that vesicoureteral reflux or ureterovesical junction obstruction was a preexisting disease; and the patient had developed complications including urinary tract infection, resulting in sepsis associated with pneumonia. The frequent vomiting was thought to be one of the symptoms arising from the urinary tract infection.

Case 7

A 2-year-old boy complained of abdominal pain in the morning, followed by vomiting several times; he then entered a state of CPA. The boy had been feeling a loss of appetite for 2 days before his death and complained of abdominal pain and vomiting 1 day before his death. PMCT of the chest showed increased attenuation in bilateral lungs (Fig. 3a), which was not seen on the chest radiograph. PMCT of the abdomen showed extensive intestinal dilatation due to much fluid retention, appearing as an air-fluid level (ileus) (Fig. 3b). Laboratory data showed leukocytosis and an elevated level of blood urea nitrogen (42.2 mg/dl) and creatinine (2.1 mg/dl). The cause of death was thought to be hypovolemic shock due to dehydration caused by systemic infection, including enteritis and pneumonia.

Case 8

A 21-day-old neonatal boy with the preexisting disease of IUGR had a sudden episode of respiratory stoppage during the day. He had been suffering from a cold for 4 days before his death. The chest radiograph showed an opaque thorax, which corresponded to hemorrhagic pneumonia.

Cases 9–14

The cause of death in six cases was thought to be pneumonia because of the patients' signs and symptoms, leukocytosis, extensively increased attenuation in the lung on PMCT of the chest, and an opaque thorax on chest radiograph.

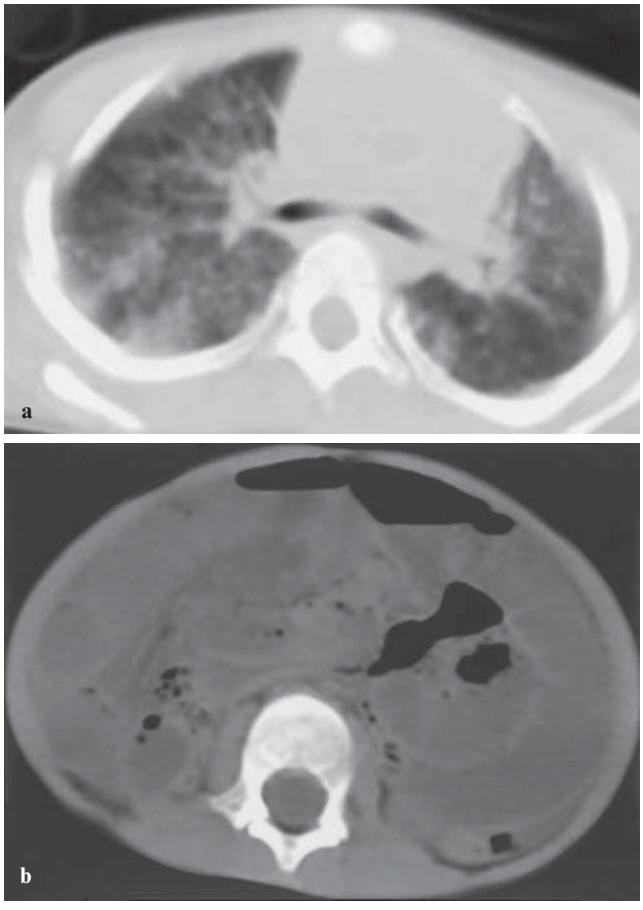

Fig. 3a,b. Case 7. A 2-year-old boy who died of dehydration caused by systemic infection including enteritis and pneumonia. **a** PMCT of the chest shows increased attenuation in the bilateral lungs. **b** PMCT of the abdomen shows extensive intestinal dilatation due to much fluid retention with an air-fluid level (ileus).

Case 15

A 5-month-old boy without preexisting disease was found in a state of CPA when he did not wake up from an afternoon nap. There were no remarkable findings before his death. Also, his medical history and laboratory data did not indicate any significant abnormality. PMCT of the chest showed increased lung attenuation in the left lower lobe only, which was localized in the dorsal side of the heart, most likely an effect of CPR. As there was no elevation of the WBC count, this case was not believed to be associated with pneumonia. The cause of death could not be detected and so was classified as unknown.[23]

Discussion

When diagnosing sudden death of infants and children, the possibility of child abuse must initially be consid-

ered. Evidence of child abuse is often difficult to detect by surface inspection alone, but postmortem imaging plays an important role in delineating evidence of child abuse.[3,24] Radiographic skeletal surveys were not done in our cases as the possibility of child abuse had been rejected based on the pediatricians' examinations, inquiries to the parents, and inquests by police. PMCT did not showed any traumatic changes indicative of child abuse.[19,20] After negating the possibility of child abuse, we then investigated the presence or absence of preexisting diseases. If there was a preexisting disease in the medical history, we presumed it to be the cause of death to some extent, together with the subject's clinical course or scene investigation. For example, sudden death due to ventricular arrhythmia often occurs after surgery for TOF (case 3).[25,26] In cases to be classified as sudden infant death syndrome (SIDS) without preexisting disease, the possibility of various infectious diseases or congenital errors of metabolism may also be considered.[27–33]

Nontraumatic PMCT findings are classified into three categories: (1) cause of death (e.g., pneumonia); (2) postmortem changes (e.g., hyperattenuating aortic wall,[34] hypostasis,[35] dilatation of the right heart[36]; and (3) changes that occurred after CPR (e.g., GI distention, hepatic portal venous gas,[16] cardiovascular gas[37]).

PMCT performed within 24 h after death generally shows brain edema.[38] In our study, brain edema was found in only four cases likely because PMCT was performed relatively soon after the confirmation of death (within 2 h). Our subjects with brain edema were all infants younger than 6 months old. With neonates, it is difficult to differentiate the reasons for low-attenuation periventricular white matter: either being in the normal range but with immature myelination or indicating hypoxic ischemic brain injury.[39] However, it is known that the death rate is high among those diagnosed as having diffuse brain edema due to an episode of violent shaking,[40] we need to investigate carefully the possibility of child abuse when brain edema is detected.

Arterial intravascular gas of the brain is considered to be a result of CPR. CVG in the right heart[37] might have been carried to the cerebral vessels from the left heart through a right-to-left shunt.[37,41]

Abnormal shadows in the lungs are better shown on CT scans than on chest radiographs. For example, for the detection of infant pneumonia, which is mainly observed as "ground-glass opacity," misdiagnosis may occur with chest radiography alone, whereas CT correctly shows it in many cases.[42] In our study, PMCT was extremely useful for showing increased attenuation in the lungs. However, increased lung attenuation is a nonspecific finding that suggests the disease but makes it difficult to differentiate between pneumonia, pulmonary edema, pulmonary hemorrhage, and complication of such diseases.[43] Moreover, in cases of SIDS, foci of acute bronchial pneumonia lesions, alveolar hemorrhage, and pulmonary edema may be seen; thus, it is difficult to differentiate death due to pneumonia from death due to SIDS.[44–46] Therefore, when we diagnosed pneumonia, we combined the findings of extensively increased lung attenuation on PMCT, signs and symptoms that suggested cold, and the presence of leukocytosis.

The value of CRP does not change much after death, so it is useful to presume that it is evidence of inflammation before death.[18] However, we did not see a significant increase of CRP, except in one case (case 6). Sudden death of infants and children in this study showed rapid progression of the disease from the onset until death; therefore, they were presumed to have died before the CRP could become elevated.

Although more autopsies are needed to make a correct diagnosis of sudden infant death, the number would not increase markedly. We think CT or MRI should be a standard screening method to detect the cause of sudden infant death in the near future. However, to establish such diagnostic methods, a larger number of radiologic-pathologic correlations (comparisons between imaging findings and autopsy findings) are necessary. This is true because, for instance, PMCT may overestimate subarachnoid hemorrhage and thus create false-positive cases.[47]

Conclusion

Determining the cause of death by surface inspection alone is generally impossible for nontraumatic sudden death of infants and children. PMCT can suggest an underlying pathology that we cannot see from a surface inspection. However, PMCT alone was not sufficient to define the cause of death. The detection rate of the cause of death was much improved when we comprehensively combined the findings of PMCT as a morphological study with the medical history, signs and symptoms, and laboratory data. In the future, inclusion of more diagnostic methods, such as viral examination, liver biopsy, myocardial biopsy, and examinations of chromosomes and genes, will hopefully help us correctly diagnose sudden infant death in cases where autopsy is refused by the family.

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