POSTMORTEM IMAGING INTERPRETATION GUIDELINE 2015 IN JAPAN

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2015 Guideline for Postmortem Image Interpretation
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Japanese edition

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Introduction

In Japan, a law to promote investigation of causes of death, the so called "Promotion of investigation of causes of death" law, was adopted at the Cabinet meeting in June, 2014. Under this law, the necessity to utilize postmortem imaging and scientific investigations to investigate the causes of death related to drugs and toxic substances is stressed. However, as postmortem imaging must be performed with a thorough understanding of all relevant issues including postmortem changes, different from a diagnosis with images of the living patients, the Ministry of Health, Labour and Welfare (MHLW) requested relevant academic conferences and the Japan Medical Association to organize workshop seminars.

The guideline here was developed as a part of the MHLW Grant-in-Aid for Scientific Research project, "Research for Implementation of Postmortem Imaging of Deaths Outside Medical Institutions" led by the principal investigator, Hideki Hyodoh, Sapporo Medical University, in collaboration with the Japan Radiological Society, the Japanese Society of Legal Medicine, and the Japan Society of Autopsy Imaging. The guideline contained in this volume is designed to provide guidelines for physicians who will keep it at hand when interpreting postmortem images. Postmortem imaging is greatly influenced by a number of conditions including postmortem interval, as well as the temperature and humidity of the place where the body has been kept. Further, it is also known that diagnostic accuracy varies depending on whether the cause of death is endogenous or exogenous. Here, some pathologists say that only autopsies are needed to investigate causes of death. However, postmortem imaging and autopsy are mutually supplementary, and a precise investigation of causes of death by autopsy also requires postmortem images. Postmortem imaging is currently performed with only CT with exceptions at some facilities in Japan, but it is known that the precision of the postmortem imaging will be improved with the use of MRI. For the convenience of readers, this guideline contains some discussion and details of ways to improve the diagnostic accuracy by MRI.

In the future, the necessity for guidelines to support postmortem image interpretation will increase as investigations of causes of death become more commonly implemented nationwide in Japan under the newly implemented law. In creating this first version of the guideline, I expect to incorporate a broad range of opinions of physicians involved in postmortem imaging by listening to publicly provided comments, mainly from members of the relevant academic societies. I sincerely wish that postmortem imaging will come to play an important role in the

death investigation system in Japan together with the presently determined autopsy findings, and that the findings will be utilized to protect the lives of the citizens of Japan.

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Note for the Compilation of the 2015 Guideline for Postmortem Image Interpretation

The development of this guideline was initiated as a part of the MHLW Grant-in-Aid for Scientific Research project in 2012 (MHLW Scientific Research Program), titled "Research for Implementation of Postmortem Imaging of Deaths Outside Medical Institutions". The project was led by the principal investigator, Hideki Hyodoh, Sapporo Medical University, in collaboration with the Japan Radiological Society, the Japanese Society of Legal Medicine, and the Japan Society of Autopsy Imaging. The project was continued as a part of the MHLW Grant-in-Aid for Scientific Research project in 2013 (Research Program to Promote the Basic Development of Community Medicine) led by the same principal investigator. We elaborated and proofread the manuscript with members of the development team and editing committee, expecting this guideline to play the role as a forerunner in the framework of investigating causes of death, as well as to serve as a standard for physicians and professionals involved in postmortem imaging. We heard that physicians in Japan engaged in the interpretation of the postmortem images experienced difficulties in interpreting images, and we decided to publish the Guideline for Postmortem Image Interpretation (Ver. 0) in March 2012, although at that point it was incomplete. We have then solicited comments made public through the Japan Radiological Society and the Japanese Society of Legal Medicine, and made modification incorporating these proposals, and have now decided to present this updated guideline (ver. 2015).

Postmortem images are also called autopsy imaging (Ai) in Japan as suggested by a previously involved practitioner. This guideline is mainly designed for postmortem imaging of corpses who died outside hospitals, and where some period of time has elapsed after death, unlike the case of in-hospital deaths. Therefore, we used the term, "postmortem images", consistently throughout. I have emphasize that using this guideline for deaths in hospitals may lead to mistaken evaluations and determinations since deaths in hospital or clinics are not covered by this guideline. Please use it carefully on your own responsibility.

Finally, I wish to express my gratitude to members of the guideline developing committee for investing the very large amounts of time they have readily provided, and to Miss. Haruna Sakurai for the invaluable work in proofreading the drafts, in a busy daily schedule with routine practice, paper work, research, and educational activities.

March, 2015

Hideki Hyodoh

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Principal Investigator of "Research for Implementation of Postmortem Imaging of Deaths Outside Medical Institutions", the MHLW Grant-in-Aid for Scientific Research project

At the Publication of the 2015 Guideline for Postmortem Image Interpretation

This "Guideline for Postmortem Image Interpretation" was developed as a part of the MHLW Grant-in-Aid for Scientific Research project, titled "Research for Implementation of Postmortem Imaging of Deaths Outside Medical Institutions" (Principal investigator, Hideki Hyodoh, Sapporo Medical University).

We requested physicians who have played an active role in radiology, emergency medicine, and forensic medicine using postmortem images to join the guideline developing committee.

The guideline is a document systematically created to support interpreters of medical images in all fields in order to be able to make appropriate evaluations in situations where postmortem image interpretation is required. Guidelines are only guidelines, and do not consider all matters that must be complied with under all circumstances. This implies that just following the letter of the guidelines will not lead to better determinations and evaluations. Further, even if a specific finding is apparently based on evidence, care must be shown in the interpretation, and independent judgment is necessary to reach a correct interpretation.

This guideline is the first edition, and there will be points where improvements in specific items and particulars are in order. I wish for physicians who use this guideline in the field of forensic medicine as a reference for evaluations and determinations to actively provide opinions to improve the guideline together with us.

March, 2015
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Background to the Development of the Guideline, and Rules and Procedures for its Use

The development of this guideline was initiated as a part of the MHLW Grant-in-Aid for Scientific Research project in 2012 (MHLW Scientific Research Program), titled "Research for Implementation of Postmortem Imaging of Deaths Outside Medical Institutions". The project was led by the principal investigator, Hideki Hyodoh, Sapporo Medical University, in collaboration with the Japan Radiological Society, the Japanese Society of Forensic Medicine, and the Japan Society of Autopsy Imaging. The project was continued as a part of the MHLW Grant-in-Aid for Scientific Research project in 2013 (Research Program to Promote the Basic Development of Community Medicine) led by the same principal investigator.

This guideline for postmortem image interpretation is prepared for physicians engaged in postmortem imaging and interpretation of postmortem images. The guideline development committee searched through and analyzed the literature using the latest databases, and structured abstracts. Based on this analysis, the committee created clinical questions (CQ), for matters which will present problems in actual interpretations. Detailed answers are provided for each CQ with objective data as far as that is possible, and recommended grades of the findings are also detailed. In assigning a recommended grade, we took the role of postmortem images into consideration by arranging them into "State evaluations" and "Cause of death identification" items. We also indicated the characteristic background to the particular state, and the characteristic findings to be expected from the images, as well as for the disease conditions, illnesses, and other particulars to pay attention to in the evaluation by adding detailed explanations to each CQ. For the references, we have indicated the search formulas, and also presented whatever documents the guideline developing committee considered to be of assistance. Further, additions by the committee are indicated with an asterisk (*) at the end of a comment in the relevant CQ. We modified the draft version by referring to comments provided publicly, and this completed the 2015 version.

The recommended grades of pediatric postmortem imaging (CQs 20-33) are described as "Recommended Grade B", when there is nothing that may be considered to impede the investigation / image interpretation, and where findings from postmortem imaging may lead to the establishment of the cause of death. Overall, we feel that this guideline is well structured as a guideline for pediatric

postmortem imaging with a full awareness of the efforts needed for the "Implementation of postmortem imaging (Ai) for all cases of child deaths" scheduled to be introduced in Japan. It is anticipated that future versions will enable more detailed elaborations as the findings from more cases are included. (Pediatric Postmortem Imaging (CQs20-33) have deleted in English version.)

For a final note, please keep in mind that this guideline does not cover some items required for interpretation of deaths in hospitals because it is designed for corpses of persons who have died outside medical institutions. Therefore, if used for deaths in medical institutions including hospitals and clinics, it should be used with care, and on the responsibility of the physicians who conduct the postmortem imaging. When filling in inquest report forms, it is not possible to make a final determination of whether a death is due to internal or external causes based on only findings of CT images. If there are matters that remain unclear, it will be necessary to indicate "unknown" and recommend further detailed examination such as autopsy. Careful evaluations by the practicing physicians are required and can be considered the basic premise for the suggestions in the Guideline.

Evidence Levels and Recommended Grades (Method of searching the literature)

Method of searching the literature for the matters detailed in this guideline

1) Using the following search formulas, 181 papers were selected from PubMed on August 7, 2013.
   #1   Search (postmortem CT) or (postmortem computed tomography)
   #2   Search (causes of death) and (autopsy)
   #3   Search (#1) and (#2)
   #4   Search (#3) and English〔Language〕Filters: published in the most recent 10 years

2) Each committee member added secondary materials in addition to the papers originally selected, and these are described in the relevant CQ.

For all papers, committee members in charge of a CQ prepared abstracts, and made evaluations according to the evidence level of the papers classified by the scientific evidence.[1]
Based on the results obtained with this procedure and referring to common, current practices in Japan, we decided on the recommended grades according to the classification method detailed in the table, and added these grades in the text when considered necessary.

Evidence levels and recommended grades used in this guideline

Evidence level [1]
1. Systematic review / Meta-analysis
2. Based on one or more randomized controlled trials
3. Based on non-randomized controlled trials
4. Based on analytic epidemiological studies (cohort study and case-control study)
5. Based on descriptive research (case report or case series)
6. Comments from the committee and individual experts not based on patient data

Recommended Grades
A. Possible to diagnose reliably with postmortem images / Postmortem imaging strongly recommended.

B. Postmortem images are very useful in the diagnosis. / Postmortem imaging recommended.

C1. Postmortem images are useful in diagnosing. / Postmortem imaging may be considered, but scientific evidence will not be conclusive.

C2. Careful evaluation is necessary to distinguish the finding from other evidence. / Postmortem imaging not recommended due to lack of sufficient scientific evidence.

D. Difficult to diagnose. / Postmortem imaging not recommended.

References

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CQ table

CQ1   What are postmortem changes that can be visualized in postmortem images?

CQ2   Are all high densities in the cranium hemorrhages?

CQ3   Can hypostasis and clotting in the heart or blood vessels be distinguished from thrombosis by postmortem CT scans?

CQ4   What are useful findings to suggest deaths due to external causes in postmortem images?

CQ5   Is it possible to exclude all deaths due to external causes by postmortem imaging?

CQ 6   In postmortem radiography, what findings are useful to determine death from natural causes?

CQ7   What are positive findings to diagnose injuries in postmortem imaging?

CQ8   Which postmortem image findings are useful for evaluating cervical spine injuries?

CQ9   Can unenhanced postmortem CT scans help diagnose an acute coronary syndrome as a cause of death?

CQ10   What are the best modalities for and acceptable findings to detect acute coronary syndrome on postmortem images?

CQ11   Can postmortem CT scans be used to diagnose pericardial hematomas?

CQ12   Can postmortem CT scans detect subarachnoid hemorrhages as a cause of death?

CQ13   Is it possible to diagnose cerebral hemorrhages which are causes of death?

CQ14   Can aortic aneurysms and aortic dissections be diagnosed as the cause of death by postmortem imaging?

CQ15   What are useful findings of postmortem imaging in the diagnosis of drowning?

CQ16   What are useful findings to determine hypothermia in postmortem imaging?

CQ17   What findings are useful in estimating starvation while alive on postmortem CT scans?

CQ18   Is it possible to diagnose malignant neoplasms on postmortem CT scans?

CQ19   Can postmortem imaging diagnose the direct cause of death due to malignant neoplasms?

CQ20   What radiological findings are useful in the diagnosis of pneumonia with

CQ1 What are postmortem changes that can be visualized in postmortem images?

Grade of recommendation: C1

> In contrast to antemortem images, many of the features of postmortem images are non-specific, including hypostasis, and hyperattenuation of structures such as the aortic walls and sinuses. These features are similar to those in antemortem images, however they may be difficult to identify on postmortem images, and therefore care must be shown when reading postmortem images (see the chart for a summary of the body sites).
>   As the postmortem image findings change and become more pronounced with time, it is also important to take into account the time elapsed since death.

Explanation

As postmortem imaging is affected by postmortem changes, it differs from imaging performed in the clinical setting. Cardiopulmonary resuscitation also affects postmortem imaging (CQ23–25). Thus, it is necessary to be careful not to mis-interpret postmortem images. It is necessary to establish "normal" postmortem image findings and features that could indicate the cause of death, and to organize this knowledge.

Postmortem changes

Biological death is confirmed following the arrest of circulation, breathing, and brainstem functioning. In dead bodies (cadavers), postmortem changes due to the arrest of circulation vary according to the time elapsed since death. These occur in the same manner as those seen on the external surface of the body; are influenced mainly by gravity and bacterial activity; and are affected by position, temperature, and the place where the dead body is stored. Changes occurring within a few days after death are termed early postmortem changes, whereas those occurring later are termed delayed postmortem changes. Early postmortem changes include falling body temperature, corneal opacity, livor mortis, and rigor mortis. Among these, livor mortis can be detected on images as hypostasis. Following the arrest of circulation, the blood in vessels and organs pools in the back and the lower parts of the body due to the effect of gravity. Hypostasis is depicted as areas of higher density than that seen in surrounding tissue, and is visualized most commonly in the area of the lungs and the intracranial sinuses. In contrast, delayed postmortem changes

include autolysis, putrefaction, skeletonization, and mummification. During putrefaction, gas forms inside blood vessels, organs, and soft tissue by the action of bacteria. The ability of computed tomography to detect gas means that gas may sometimes be depicted as early as a few hours after death.

Postmortem image findings

Postmortem image findings comprise the antemortem clinical conditions causing death, those due to cardiopulmonary resuscitation, and postmortem changes. The changes due to cardiopulmonary resuscitation include those caused by chest compression (closed-chest cardiac massage), artificial respiration, and other treatments administered at cardiopulmonary arrest (CQ23-25). Typical postmortem changes that do not normally appear in antemortem images are listed in the *table*; these include hypostasis (CQ3) and gas from putrefaction. These changes are non-specific in postmortem images, and do not imply abnormal findings (*figure*) [1][2].

 Even if the postmortem findings are similar to those in antemortem images, the underlying pathological mechanism and interpretation of the findings may be different [1].

It should be noted that here we discuss characteristic normal postmortem findings, rather than provide an exhaustive list.

The longer time has passed, the stronger the postmortem changes appear

A study performed by computed tomography immediately after death and again at more than one day after death found that the later images were influenced and modified by postmortem changes, and that these changes could cause misinterpretation. Images obtained immediately after death are only little influenced by postmortem changes, and are therefore suitable for determining the cause of death or the course of illnesses, while those obtained more than one day after death reflect the findings of a pathological autopsy. It is necessary to have an understanding of the differences and characteristics to enable these two phases of postmortem images to be utilized. Repeated scans at different time periods and comparisons with an autopsy will enable improvement in our knowledge of postmortem changes and thus increase the accuracy of image interpretations.

As the postmortem changes themselves change over time, the time elapsed since death is an important factor that should be carefully considered when interpreting postmortem images.

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3. Shiotani S et al: Postmortem pulmonary edema: a comparison between immediate and delayed postmortem computed tomography. Leg Med (Tokyo) 13: 151-155, 2011 (Level 5)

Figure

Postmortem chest CT scan showing hyperattenuation of the aortic wall and hypostasis.
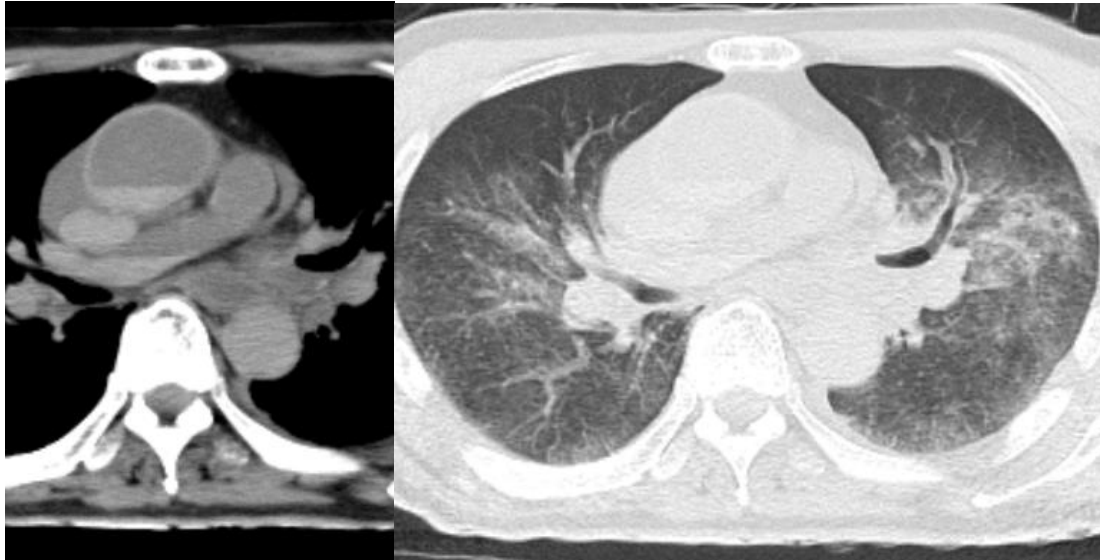
(A) The wall of the enlarged ascending aorta shows high attenuation (▲). There is a clear separation between areas of higher and lower attenuation, which form a level perpendicular to gravity (→). The appearance of hypostasis is similar to that of erythrocyte sedimentation.

(B) Ground glass attenuation is evident throughout the lung area, and is more prominent in the lower part of the body than on the ventral side (→). The appearance is characteristic of hypostasis.

Table

Characteristic postmortem CT findings of a traumatic death (cited from references 1, 2; partly modified)

Chest	Abdomen
aortic dissection rupture of aortic aneurysms ischemic heart disease (pulmonary edema due to pumping dysfunction) pulmonary thromboembolism (enlargement of the hilar pulmonary artery)	rupture of aortic aneurysms intraperitoneal free gas (gastrointestinal perforation)
cardiovascular gas rib fractures	intrahepatovascular (portal and hepatic veins) gas dilation of the gastrointestinal tract
hypostasis (cardiovascular system, lungs) enlargement of the right side of the heart hyperattenuation of the aortic wall	intrahepatic gas
decomposition (intravascular gas)	decomposition (intravascular gas)

CQ2 Are all high densities in the cranium hemorrhages?

Grade of recommendation: C2

Intracranial high densities may appear in some non-hemorrhagic states or as postmortem changes on postmortem head CT scans. It is known that hypostasis in the dorsal venous sinuses show as high densities. Cisterns may show high density as in case of sequels to cerebral edemas in acute cerebral infarctions and also in other cases. Such non-hemorrhagic states must be distinguished from intracranial hemorrhages.

Explanation

Head CT scans are useful to diagnose intracranial hemorrhages, which present high densities, clinically. High densities due to postmortem changes or non-hemorrhagic states, which resemble intracranial hemorrhages, must be distinguished from intracranial hemorrhages on postmortem CT scans.

## Intracranial high densities as a postmortem change

It is known that hypostasis in the dorsal venous sinuses show as high densities. In some reports, the autopsies have established that cranial high densities on postmortem CT scans were normal venous sinus or congestive cerebellar tentorium. In particular, hypostasis is clearly observed in neonates and infants. Because of the high water content of the brain, brain parenchyma shows low attenuation shapes on head CT scans. Hypostasis is commonly observed along the falx cerebri, or bilaterally symmetrical dorsal sinuses.

Intracranial high densities due to brain edema

Intra-cistern high densities, which are known as Pseudo-subarachnoid hemorrhages, may be seen (occur) in patients with cerebral edema due to acute cerebral infarction, and for other reasons. Such findings may be seen on post-mortem CT scans in decedents with acute cerebral infarction with cerebral edema.

Figure

high density at the posterior fossa
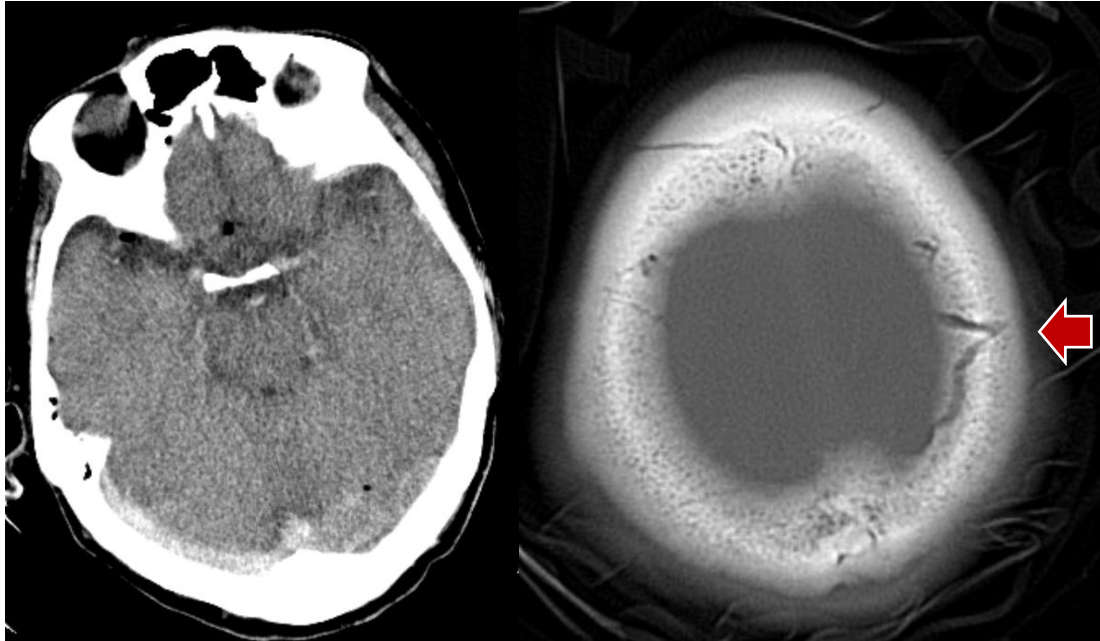
High density present at the superior sagittal and transversus sinuses, resembling subdural hematomas.

This CT image was reported for a skull bone fracture and subdural hematoma. At the autopsy, there is no skull bone fracture and no subdural hematoma. The arrow is the diploic vein (canal).

CQ3 Can hypostasis and clotting in the heart or blood vessels be distinguished from thrombosis by postmortem CT scans?

Grade of recommendation: C2

Hypostasis and clotting in the heart or great vessels which appear after the cessation of circulation are often observed on postmortem CT/MRI scans. It is thought that there is a possibility of misdiagnosis because these postmortem changes are similar to thrombosis in living humans. There are a number of reports of the features of hypostasis and clotting like the postmortem changes or thrombosis as a pathologic condition, however, the diagnosis of thrombosis by postmortem CT/MRI images needs to be made with great care.

Explanation

hypostasis, sedimentation

Hypostasis occurs after circulation has ceased. The plasma and cellular components of the blood are subject to gravity and initially sink and become sediment in the heart and vascular system. Hyperdense areas on the dependent side and hypodense areas on the independent side with mirror surfaces exhibit hypostasis on PMCT [1]. On postmortem MRI scans, hypostasis is observed as low signal intensity areas on the dependent side (due to the iron content of the hemoglobin in sedimented red blood cells) and high signal intensity areas on the independent side of T2-weighted images. However, this state does not show steady signal because the postmortem elapsed time can affect MR signal intensity [2]. It is reported that the clarity of hypostasis on postmortem CT scans differs among cases and is related to the antemortem serum fibrinogen score [3]. The status such as the position or temperature of preserved cadavers may affect findings of hypostasis.

intravascular clotting

Blood clotting as a postmortem change is considered to occur in the state of long agonal stages or chronic disease deaths. Clotting varies in density and form, and "mold-like" hyperdense columnar structures similar to pulmonary arterial thrombosis are often observed [4-7]. It is considered that the formation of clotting is a gradual postmortem change and hypostasis is sometimes noted in the clot. The parallel occurrence of hypostasis becomes uncertain as broad clotting includes many blood cells. Clotting is also affected by the situation of the death or temperature of

the preserved cadaver and possibly occurs in situations such as deaths by freezing or burning [8,9]. In addition, hypostasis and clotting is easier identified on MRI than on CT scans [2].

Distinguishing of hypostasis and thrombosis
pulmonary artery thrombosis

Takahashi et al. reported a case of pulmonary arterial thrombosis which was suspected by a postmortem CT scan and proved by the autopsy. Dilatation of the hilum pulmonary artery and narrowing of peripheral pulmonary artery thrombosis were observed on the postmortem CT scan [10]. Some clinical studies report that acute pulmonary artery thrombosis may to some degree be diagnosed by unenhanced CT scans [11,12]. It is considered that thrombi are easily identified in the middle of the side of the pulmonary artery and that the density of the thrombi varies. Although secondary findings of dilatation of the pulmonary artery which reflects pulmonary hypertension due to pulmonary arterial thromboembolism or of the right heart are occasionally observed on postmortem CT scans, it is necessary to carefully interpret these findings because dilatation of the right heart occurs as a normal postmortem change due to the cessation of circulation [13]. When pre-mortem pulmonary thrombosis is suspected by a postmortem CT scan, it is difficult to distinguish between acute and chronic pulmonary thrombosis. The form of chronic pulmonary thrombosis varies from band-like to meshed and others [14].

On postmortem MRI images, the finding of blood clots before death sometimes reflects the deposit of hemosiderin. Therefore, postmortem MRI scans can possibly distinguish acute from chronic thrombosis [6]. It is reported that hypostasis in blood clots before death are not observed and that such clots show a homogeneous form continuous with the vascular wall [15]. However, there are also reports that blood clots as a postmortem change in the cardiac cavity are not adjacent to the ventricular wall [6,7]. The localization and form in the cardiac or vascular lumen, its angle, and irregularities of the border of the density/signal may be helpful in a differential diagnosis of hypostasis, clots, and/or thrombosis on postmortem CT/MRI images.

Hypostasis reflected in postmortem changes or blood clots are often observed on postmortem CT/MRI images, and it may be difficult to establish diagnoses of these findings and pulmonary artery thrombosis on unenhanced CT/MRI images. However, it may be possible to suspect pulmonary thromboembolism by evaluating the form or density of the pulmonary artery (referring to multi-planar reconstructed

images). Additionally, Clinical information such as sudden chest pain, dyspnea, cardiopulmonary arrest, and similar will be useful.

Recent studies by Jackowski et al. show that thromboembolisms can be distinguished from blood clots on postmortem unenhanced 3T-MRI images.

coronary artery thrombosis

Jackowski et al. reported that thromboembolism of the left anterior descending artery could be diagnosed on postmortem MRI images. Thrombus should be suspected because homogeneous light, high signal intensities without hypostasis in the narrowed arterial lumen has been established in T2-weighted images [17]. Low signal intensity findings between the anterior and base walls and the ventricular septum on T2-weighted images with suspected hyper-acute myocardial ischemia supported the diagnosis of coronary artery thrombosis.

Michaud et al. reported that hypostasis in the ascending aorta extended to the left coronary artery and blood clots were formed in the coronary artery [18]. The important point here is that clots in the coronary artery were not diagnosed as thrombosis. Hyperdensity in the coronary artery with continuity to the obvious hypostasis in the ascending aorta should not immediately be diagnosed as thrombosis and this leads to the possibility of disregarding the diagnosis of thrombosis here. Conversely, it is considered that excluding thrombosis is difficult when hypostasis and blood clots are not clearly identified.

Remarks

Thrombosis of the pulmonary artery and coronary artery is mentioned in this section. Further studies of other kinds of thrombosis such as pulmonary vein or sinus thrombosis can be expected to be reported.

Research methodology and supplementary materials

The following terms were searched for on PubMed: postmortem, forensic, CT, computed tomography, MRI, magnetic resonance imaging, thrombosis, thrombus, embolus, embolism, hypostasis, sedimentation, clot, clotting, coronary, pulmonary, thromboembolism. Books entitled "autopsy imaging guide for interpretation" and "autopsy imaging cases series" were also used in this survey.

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Figure

An autopsy case of a pulmonary thromboembolism
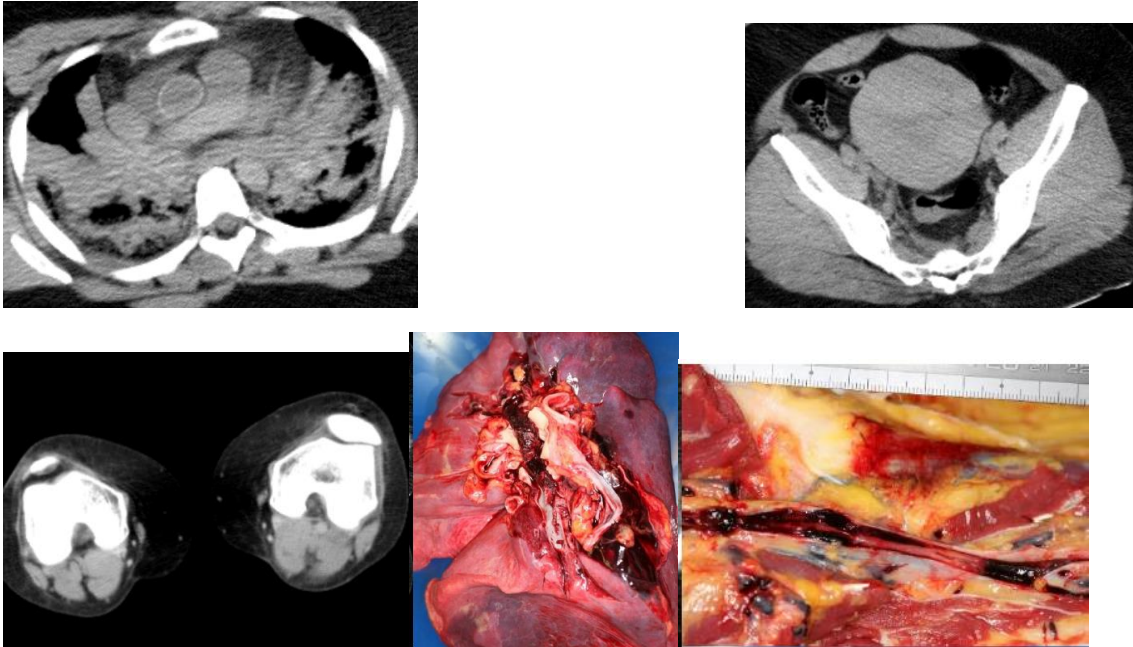
Although the pulmonary artery seems to be dilated compared with the aorta, a finding that suggests blood clot or thrombus in the main trunk of pulmonary artery is not observed. It is observed that significant bilateral consolidation is mainly in the hilum (A). A uterus tumor is observed in the pelvis and a finding of iliac artery and vein compression by this tumor is observed (B). Comparing with the right popliteal vein, the left popliteal vein is tense and hyperdense (C). The autopsy showed thromboembolism in the bilateral intrapulmonary arteries (D). Thrombosis in the vein of the left popliteal fossa and lower leg muscle were also identified (E) the arrow in the cranial side).

CQ4 What are useful findings to suggest deaths due to external causes in postmortem images?

Grades of recommendations: C1 for evaluating the condition
C2 for determining the cause of death

The findings that are useful to suggest deaths due to external causes include trauma such as bone fractures or subdural hematomas, drowning-related findings, findings associated with neck compression such as hyoid fractures, foreign objects in the airways, overdose-related findings in the stomach, hypothermia-related findings, gas embolisms, and abuse-related findings.

Explanation

The definition of deaths due to external causes

Deaths due to external causes are all kinds of causes of death except "deaths by diseases and natural deaths" and "undetermined deaths" as detailed in death certificates in Japan [1]. In death certificates in Japan, deaths due to external causes are classified into unexpected accidental deaths (traffic accidents/ falling/ drowning/ injuries due to smoke, fire, and flames/ asphyxia/ intoxication/ and others) and other deaths due to external causes (suicides/ homicides/ causes undetermined). As emphasized in the guidelines for unnatural deaths produced by the Japanese Society of Legal Medicine [2], deaths due to sequela or after effects of injuries from external causes or deaths associated with medical treatment must be treated as deaths due to external causes. However, these kinds of deaths are not included in this section because the present guidelines are for dealing with deaths from undetermined causes occurring outside hospitals.

Background

In this section, only postmortem computed tomography (PMCT) studies without using contrast media are included because this is the most used modality for postmortem images in Japan.

Although there are some studies referring to the possibility of determining causes of death by PMCT scans based on comparisons with autopsy results, most of these discuss only "causes of death" [3-8]. Few discuss the "manner (way) of death" including deaths caused by external causes. Generally, as in some of these reports,

the "manner of death" can be determined only in comprehensive ways using all of the information associated with the cadavers involved, including investigation of the situation by law enforcement officers, or toxicological findings, and are never determined simply by findings based on images.

In Japan, even if a cadaver is discovered outside hospitals, once law enforcement officers establishes that it is not related to a crime, autopsies are not to be performed. However, in some of such cases, PMCT scans are still made, and the PMCT scans may show findings suggesting death due to external causes, which law enforcement officers probably would not have expected before the scan was available [9,10]. Sometimes law enforcement officers initially suspect death by disease, but PMCT scans find this to be wrong [11]. In this situation, the PMCT scan reader who makes this discovery must persuade the police to change their determination. It may be said that for PMCT scan readers of cadavers discovered away from hospitals, a minimal requirement would be to check for the presence or absence of findings suggesting deaths due to external causes in deciding the causes of death.

In the following several sections, simple explanations and caution related to image findings of different kinds of deaths due to external causes are detailed. As these topics are also discussed in other sections of this guideline, it is recommended to check the respective sections of this book for the different topics.

Trauma deaths

For 5 of 20 cadavers Hayakawa et al. reported that PMCT scans showed findings suggesting deaths due to external causes which were not initially identified by external examinations. In 3 of the 5 cases, the findings were related to trauma (2 to subdural hematomas and 1 to liver contusion) [9]. For 10 of 80 cadavers Iwase et al. reported that PMCT scans showed findings suggesting deaths due to external causes. In 7 of the 10 cases, the findings were related to trauma (4 to subdural hematomas, 1 to stab wounds to the heart, 1 to traumatic tension pneumothorax, and 1 to abdominal organ injury) [10]. For 3 of 494 cadavers that were initially thought to be from deaths by diseases, Takahashi et al. reported that PMCT scans showed trauma including 2 of multiple trauma and 1 of cervical neck injury. As these reports from Japan show, the most common findings suggesting deaths due to external causes which were not initially detected by external examination or police investigations is trauma. This suggests the need for PMCT scan interpreters to pay attention to possible hidden trauma symptoms in reading the images.

In multiple reports comparing PMCT scan observations with autopsy findings,

agreement with trauma-related findings was confirmed [3, 4, 6-8, 12-17]. In a meta-analysis performed by Scholing et al., agreement between the PMCT and autopsy findings of traumatic deaths reached 46-100% of the causes of death, and 53-100% in the specific trauma determined[17]. Further large-scale research is needed to narrow these large differences. However, they show that at least about half of trauma cases can be detected by PMCT scans. The trauma findings, which are referred to as detectable lesions by the PMCT scan readings similar to autopsies in many reports, are bone fractures and fatal hemorrhages inside the cadavers such as intracranial hematomas or retroperitoneal hemorrhages. These findings need PMCT scans for the detection, but as these reports suggests, attention is required for trauma detection because even fatal trauma can be missed by PMCT scans in some cases. This is emphasized in detail in CQ5.

Drowning

As stated in CQ15, the findings suggesting drowning include fluid collection in the paranasal sinuses, fluid collected in the trachea and bronchi, and ground-glass opacities in the lungs and all have been reported [18]. If the PMCT scan readers are familiar with these findings, it becomes possible to assume drowning as a cause of death by looking at PMCT scans, at least to some extent. However, these PMCT scan findings are non-specific, and for an accurate diagnosis of drowning the diatom detection inside the bodies and excluding other causes of death are needed, something which PMCT scans cannot achieve. Besides, to determine why the cadaver came to be in the water (accident or pushed by someone) it is recommended to consult autopsies and law enforcement authorities.

Fire related deaths

The findings to be evaluated for a diagnosis of fire-related death include soot in the airways, blood concentration of carbon monoxide, and extent of burns, none of which can be evaluated by PMCT scans. However, PMCT scans are useful to determine whether a cadaver was shot or not prior to the autopsy [19,20] since gunshot wounds exposure to soot is difficult to evaluate from external examinations of charred cadavers. Levy reports that PMCT scans are also useful to evaluate whether skull fractures are traumatic or occurred postmortem, formed by heat [19]. Overall PMCT scans are useful to determine unexpected causes of death due to external causes in fire-related cases.

Asphyxia

There are PMCT scan findings suggesting asphyxia due to neck compression (hanging, strangulation, manual strangulation), and fractures of cervical bones and cartilage such as hyoid fractures [8,21]. Further, it is reported that foreign objects in the airways can be identified by PMCT scans, which is useful to determine asphyxia due to aspiration of foreign objects [22, 23] (CQ21).

Much caution in interpreting images on this topic are necessary, including: that there are no other useful findings to detect some kinds of asphyxia especially suffocation due to obstruction of the orifice of the mouth and nose, that no fractures occur in many cases of neck compression, and that PMCT scans are not useful to show vital reactions of asphyxia including petechiae, showing that great care must be shown before deciding on a cause of death here.

Intoxication

As a diagnosis of death due to intoxication needs toxicological examinations from cadaver samples like femoral blood, there are no definite findings to determine intoxication deaths by PMCT scans. However, as in CQ22, there are cases of overdoses, high-density gastric and duodenal contents derived from ingested tablet components that can be detected by PMCT scans, and PMCT readers need to pay attention to, as these could be a key to establish death by intoxication [24].

Others

It may be necessary to look for findings suggesting hypothermic states at death (low-density lungs, clot formation inside the heart and aorta, increased urine volume in the bladder) [25, 26]. Care must be taken for such a diagnosis because hypothermic death needs to consider reasons why the victim could not escape from the cold environment (CQ16).

Gas embolism is a very rare cause of death due to external causes. There are many case reports of PMCT scans which detected intravascular gas in suspected cases [27-29]. Intravascular gas can also be generated postmortem and it is important to know the "normal" postmortem gas distribution for a diagnosis of gas embolisms.

If PMCT scans show findings suggesting chronic physical abuse such as old rib fractures in the cases of child deaths, deaths due to external causes must be considered, even if the findings are not sufficiently serious to be fatal [7] (CQ31).

*Deaths due to external causes are classified into "manners of death", and these

cannot be determined without investigations performed by law enforcement officers and autopsy results including toxicological examinations. If PMCT scan readers identify findings suggesting deaths due to external causes, these readers must at least be able to persuade law enforcement officers to reconsider conclusions with newly established findings.

Search formula・secondary references

The authors performed the search on Pubmed for the past 10 years using combined keywords as follows; "postmortem CT" or "postmortem imaging" or "forensic radiology" or "virtual autopsy" or "virtopsy", autopsy, cause of death, and trauma. Besides, the manual for death certificates (2014) (from the homepage of the Health, Labour and Welfare Ministry http://www.mhlw.go.jp/toukei/manual/) [1] and the manual for unnatural deaths produced by the Japanese Society of Legal Medicine (from the homepage of the Japanese Society of Legal Medicine http://www.jslm.jp/public/guidelines .html) [2] have been consulted.

Reference

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CQ5 Is it possible to exclude all deaths due to external causes by postmortem imaging?

Grade of recommendation: D

There are some deaths due to external causes such as intoxication or some cervical cord injuries that will not yield positive findings by PMCT scans. Also, some positive findings likely to be diagnosed as deaths by diseases such as subarachnoid hemorrhages, cerebral infarction, or rupture of aortic aneurysms have the potential to be diagnosed as deaths due to external causes depending on the situation. Thus, it is not recommended to use postmortem imaging to rule out deaths due to external causes and careful evaluation is needed.

Explanation

Background

It may be that non-contrast postmortem computed tomography (PMCT) studies suggest deaths due to external causes even if police officers initially have already determined that the cadaver has no relation to a crime[1,2]. Suspicion of death due to external causes can be provoked for the first time by PMCT scans even if physicians initially consider that a case was death by disease[3].

Comparison studies between PMCT scans and autopsies (CQ4)

Deaths due to external causes are classified into different "manners of death", which should be determined from autopsy results as well as from comprehensive information including investigations to determine details of situations and toxicological examinations. There are no studies that have concluded that only PMCT scans can finally decide the causes of deaths due to external causes comparing determinations by PMCT scans and autopsies.

Continuous case series studies with relatively high volumes of cases, all have concluded that PMCT scans cannot diagnose intoxication or fire-related deaths [4-8]. For drowning, there are some reports saying that this can be diagnosed by PMCT scan findings, but most have concluded that the findings are non-specific and that a definite diagnosis by PMCT scans alone is difficult. This is similarly said for asphyxia cases.

Even traumatic deaths, which are thought to be the simplest to detect by PMCT scans among deaths due to external causes, there is a wide-range of successful

detection with (50-100%) depending on the report[9]. Reasons for the low detection rate of trauma by PMCT scans are that it is difficult to detect some causes of fatal trauma including vascular injuries, cervical cord injuries, lung contusion, and liver contusion. It is also important to be aware of the difficulty to know whether signs of trauma are formed antemortem or postmortem, here the detection rate of "vital" trauma cases would decrease further[4,8,10].

There are some deaths due to external causes that appear like deaths by diseases on PMCT images. For example, it is also stated in the topic of subarachnoid hemorrhages in CQ12, that there are cases of traumatic rupture of the vertebral or basilar arteries with large amounts of subarachnoid hematomas on the basal cisterns misleading readers to diagnose this as subarachnoid hemorrhages due to rupture of cerebral artery aneurysms[6]. This could similarly occur in traumatic cerebral infarctions, traumatic cardiac tamponade, or traumatic ruptures of aortic aneurysms.

In summary, when considering the many problems detailed above, it seems difficult to exclude all deaths due to external causes only by PMCT scans. To determine to exclude deaths due to external causes, careful evaluations are needed from PMCT scan findings as well as from comprehensive information such as the investigation information from law enforcement officers or results of toxicological examinations.

Search formula・secondary references

The authors performed the search on Pubmed for the past 10 years using combined keywords as follows; "postmortem CT" or "postmortem imaging" or "forensic radiology" or "virtual autopsy" or "virtopsy", autopsy, cause of death, and trauma.

Reference

1. Hayakawa M, et al: Does imaging technology overcome problems of conventional postmortem examination? Int J Legal Med 120:24-6, 2005（levelⅤ）
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CQ 6 In postmortem radiography, what findings are useful to determine death from natural causes?

Grades of recommendations: C1 for evaluating the condition
C2 for determining the cause of death

Extravascular retention of bleeding such as from cerebral hemorrhages or hemopericardium (hematomas in the cardiac sac) by aortic dissection, is useful in the diagnosis of diseases as internal causes of death. Depending on the degree, it may be considered to be deaths from internal causes.
Refer to other chapters CQ6-9, CQ15-16 such as for Subarachnoid hemorrhages (→ CQ7), Cerebral hemorrhages (→ CQ8), Aortic dissections (→ CQ9).
It is thought that disease findings for clinical diagnosis are also useful.
We consider such findings for the disease. We have to examine carefully to determine a disease as the cause of death, while external causes of death should be excluded

Explanation
Definition of an internal cause of death
Internal cause of death is used as the opposite of "external cause of death", the so-called natural death.
Those refer to death due to natural diseases other than trauma or causes by foreign substances / environment, however, including deaths from infection of microorganism such as viruses or bacteria.

The postmortem CT scan findings useful for diagnosis of an internal cause of death
In determining the cause of death, it is very important to distinguish internal from external causes in the view of forensic medicine. As image findings, we deal with findings of clinical diseases. There are some cases where it is difficult to make a determination even from autopsy findings.

1. Findings to indicate diseases that are important
It is useful to establish findings of hemopericardium with aortic dissection and a post MI cardiac rupture among disorders of the heart and large vessel system. It can be a ground for a determination to specify the site of a rupture by postmortem angiography. (10)

2. It is more difficult to diagnose natural deaths than deaths from external causes. (39)

Brain subarachnoid hemorrhages

Subarachnoid hemorrhages may be strongly suspected as the cause of death, especially when there is a dense subarachnoid hemorrhage at the base of the brain, subarachnoid hemorrhage with intraventricular hemorrhage, and subarachnoid hemorrhage with pulmonary edema. (CQ7)

Cerebral hemorrhage

Cerebral hemorrhages can be strongly suspected as the cause of death when there is brain stem hemorrhage, bleeding of more than 30 cm^3, bleeding to overcome or pressure the ventricle, cerebral hemorrhage with a midline shift of 5 mm or more. (CQ8)

Hemopericardium (hemorrhage in the cardiac sac)

When we observe a high density area occupying pericardial space, the presence of a hemorrhage in the pericardium can be recognized. Large hemorrhage quantities indicate suspects for the cause of death.

It is difficult to show the cause of bleeding and to diagnose the primary cause of death.

Post MI cardiac rupture, aortic dissection and pericarditis should be diagnosed differentially. (CQ?)

Aortic aneurysm ruptures / Aortic dissection

We can determine this disease when there is a large quantity of bleeding.

When there are pools of blood, applanation of large vessels, rhexis of vascular tissue with false cavities and circulation oligemia, this can be strongly suspected. (CQ?)

Malignant tumor

We can point out tumors such as malignant tumors of lungs, bronchi, a pleura, a pharynx, bowel, liver, brain, and adrenal. However, it is difficult to diagnose an origin and tissue form of a tumor or whether it is primary.

We should diagnose totally findings about sequence syndrome, but it is difficult to determine the cause of death only with postmortem images. (CQ15)

Pneumonia

If there is a regional invasive shadow or multiple fusion spotted invasive shadows, there is a possibility of pneumonia. In addition, it is important to distinguish these findings from pulmonary blood hypostasis, lung congestion and pulmonary edema. You should not assume pneumonia as the cause of death only with an image. (CQ16)

About each finding, it should be referred to CQ6 -9, CQ15 -16.

It is necessary to examine carefully whether you exclude external fatal causes.
We always have to take it into consideration that there are functional diseases or poisonings that are impossible to determine only by postmortem images.

PubMed and search using the keyword postmortem.

Reference

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CQ7 What are positive findings to diagnose injuries in postmortem imaging?

Grade of recommendation: C2

There are two positive findings to diagnose injuries, which are findings from inside of the body created by external forces and findings of the objects which produced the external force.

Contusions of organs, deformity or translocation of organs/bones indicate damage to the body affected by an external force. Presence of ectopic liquids like blood indicates that the liquids have been translocated by the external force, bleeding. Presence of ectopic gas/air indicates that the gas/air have been translocated in the body by an external force or that the gas/air has penetrated into the body through the area of injury. If there are foreign objects, fragments of sharp or blunt objects, or bullets in the body, they are objects which penetrated the body.

Additionally, caution is needed since signs of fatal damage to the organs can be overlooked in postmortem CT scans.

Explanation

Definition of injury

An injury (or wound) can be explained as damage to the human body due to the application of mechanical force. A weapon is defined as an object which produces an injury.

Mechanism of injury is explained as how the injury has been produced.

It is important to determine the presence of injuries from the standpoint of forensic medicine.

Useful CT findings to diagnose injuries

It is known that positive agreement rates between antemortem and postmortem CT findings are high since CT scan findings of injuries are less affected by the postmortem interval [1].

Findings of damage in the body effected by an external force: fractures of the bones, contusions of the organs, deformity or translocation of organs/bones

While CT images are useful in diagnosing fractures of bones [3], humeral fractures are likely to be missed when they are outside the parameters of the scan (upper extremity and below the knee) (Fig. 1) [3]. Further, CT images are also useful in the

case of road traffic accidents in which the manner of death is clearly established based on the circumstances of the case, but the mechanism and the exact cause of death cannot be ascertained based on external inspection [4]. Although the most commonly injured organ is the liver in blunt abdominal trauma [5], life-threatening liver laceration may be missed by CT scans [6]. Injuries which are difficult to detect by CT scans are bleeding in soft tissue, splenic laceration, thyroid contusion, mesenteric lacerations, and others [2,3].

Presence of ectopic liquids/gas translocated by external forces: blood (bleedings), gas

 The following are regarded as characteristic changes of a pericardial rupture after a blunt trauma to the chest: focal pericardial dimpling and discontinuity, pneumopericardium, interposition of a lung between: aorta and pulmonary artery; or heart and diaphragm; or right atrium and right ventricular outflow tract. Characteristic changes for a cardiac herniation include: "Empty pericardial sac" signs, air outlining the empty pleuropericardium as a result of cardiac luxution into the hemithorax [7].

Postmortem CT scans can be a useful tool to detect the gas in the abdominal cavity, emphysema or intramuscular bleeding which may be missed by an autopsy [2,7]. In the case of traumatic pulmonary air embolisms, the cause of death as determined by post-mortem CT scans may differ from the autopsy based determination of the cause of death [2].

Findings of air penetrated into the body through the area of injury: gas/air pattern

In the case of stab wounds, the stab channel may be clearly visible due to the influx of air [8].

Foreign bodies penetrating the body: sharp objects, blunt objects, or bullets

In the case of impalement injuries (defined as the penetration of an elongated object into the human body), the perforating foreign body may be displayed on the image (Fig. 2) [9]. In the case of gunshot injuries, foreign objects such as bullets or metal fragments may be detected, something which helps to diagnose old gunshot injuries [10]. The entrance and exit wounds of a gunshot can be detected even in the case of badly destroyed bodies (due to fire) [2]. Postmortem CT scans will be essential in the examination of ballistic trauma [2].

Reference

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Figure

a case of a road traffic accident (runover)

Fracture of the left humerus and the ribs indicate a strong power (pressure or contusion) from the left side. The axial image of the chest (A) displays the right pneumothorax, left hemopneumothorax, emphysema in the left side chest wall muscle, gas patterns in both ventricles, and the dislocation of the heart to the left thoracic cavity. The 3D volume rendered image (B) shows an obvious deformity of the left upper limb and the thorax, which indicate the direction of the external power.

Figure

a case of impalement injury
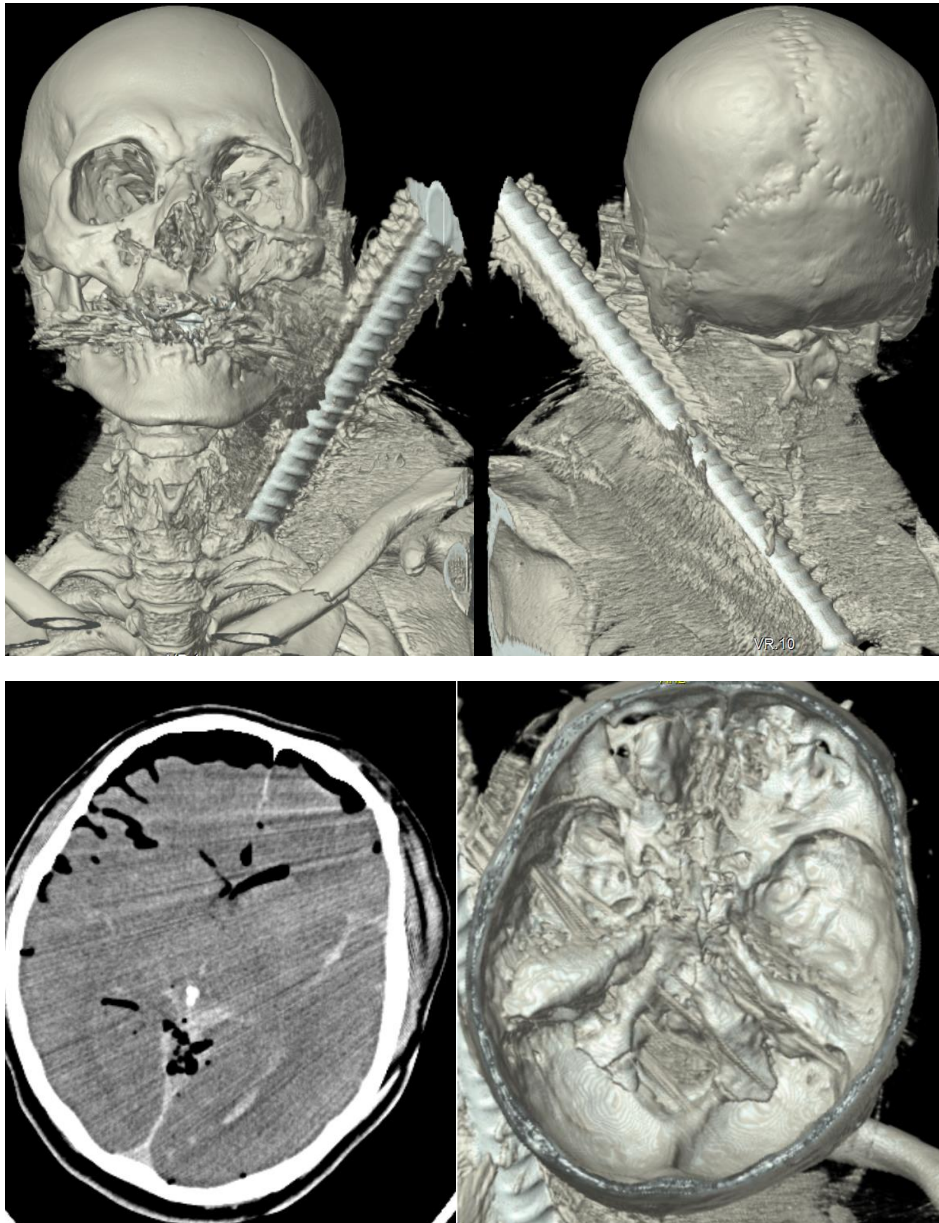
The 3D volume rendered images (A, B) display a rebar perforating the body from the left front to the back of the chest and fractures to the head (the facial bone and the skull). There are gas patterns and a subarachnoid hemorrhage in the cranial cavity (C). The 3D image of the skull base (D) shows a longitudinal fracture of the skull base from the left front to the right back of the skull base and a ring shaped fracture around the foramen magnum (‣)

CQ8 Which postmortem image findings are useful for evaluating cervical spine injuries?

Grades of recommendations: C1 for evaluating the condition
C2 for determining the cause of death

The postmortem CT findings of cervical spine injuries include cervical spine fractures, dislocations, and edema and hematomas around the cervical spine. Postmortem MRI scans may show injuries to the spinal cord, intervertebral disks, and spinal ligaments. These findings are in principle the same as those of cervical spine injuries on antemortem images. However, care is needed with regard to one issue specific to postmortem images: it is difficult to determine whether the trauma occurred before or after death, even when a cervical spine injury is determined. In addition, atlantoaxial rotatory fixation may be over-diagnosed due to abnormal positioning of the spine in rigor mortis.

Explanation

Definition of cervical spine injuries

Cervical spine injuries result from direct/indirect trauma to the cervical spine, and can include cervical fractures, dislocation, and intervertebral disk injuries. It is caused by movements that exceed the normal range of cervical motion, such as overextension, overflexion, rotation, compression, and extension that may occur in traffic accidents or in falls from great heights (Figs 1, 2). Cervical spine injuries are classified as upper (C1–2) and lower (C5–7), and are commonly accompanied by injuries to the spinal cord (Fig. 3). Extensive injuries to the spinal cord above the C4 level may result in death.

External and internal findings for cervical spine injuries

External findings such as cervical edema are sometimes apparent, but intensive internal injuries may occur even in the absence of obvious external findings, and it is important not to overlook a cervical injury when there is damage to the head and face. Cervical injuries can be difficult to determine because of rigor mortis; however, an abnormal range of movement is highly suggestive of injury to the cervical spine and spinal cord [2]. Hematomas may be caused to various extents by fractures or injuries to the intervertebral disks and spinal ligaments, among other causes. Injuries to the cervical spinal cord cause cervical swelling due to edema and

hematomas, and rupture of the spinal cord is often accompanied by intensive injuries.

Selecting the appropriate modality: chest X-ray, CT, or MRI scans

Technological developments in CT scanning have enabled the production of sagittal multi-planar reconstructions with minimal image deterioration. In cases where cervical spinal injuries are strongly suspected, CT scans are superior to chest X-rays for establishing the presence of cervical spinal injuries such as fractures and dislocations [3]. Thin-slice CT scans are ideal for this purpose; when many slices are obtained, images reconstructed at a thickness of 3 mm are useful for the diagnosis [4]. With MRI scans, lesions can be detected in the cervical spinal cord, intervertebral disks, and spinal ligaments, and it is possible to diagnose injuries to the cervical spine (including fractures and damage to the spinal cord). With MRI scans it is also possible to depict edema and hematomas resulting from cervical spinal cord injuries; however, the ability of MRI scans to detect cervical spine fractures is only similar to that of plain X-ray images, as reported in a previous study of antemortem imaging [5]. So, CT scans are therefore superior to MRI for detecting fracture lines and small bone fragments. Still, as many reports have indicated the usefulness of MRI for detecting injuries to the cervical spinal cord [6]-[8], postmortem MRI scans should be provided where possible.

Existing knowledge of image features of cervical spine injuries on postmortem CT and MRI scans

Previous reports of postmortem CT scanning have described the following features of cervical spine injuries: cervical spine fractures, dislocation, and edema and hematomas around the cervical spine [6]-[11]. It is considered that fractures are more easily identified on CT scans than at an autopsy, whereas dislocation is more difficult to identify on CT scans than with an autopsy [6]. In addition, postmortem MRI scans have been reported to enable visualization of injuries to the cervical spinal cord, intervertebral disks, and spinal ligaments [6]-[8].

In antemortem images, the term "spinal cord injury without radiographic abnormalities (SCIWORA) syndrome" is used if no abnormalities are apparent on CT scans, despite intensive trauma that has caused clinical cervical spinal cord injuries [12]. As similar instances have been reported in postmortem imaging [6][9], it is necessary to be aware that the possibility of spinal cord injuries cannot be completely ruled out even if there are no apparent significant abnormal findings.

A problem specific to postmortem imaging here is that in the absence of obvious hematomas, it is often difficult to tell whether the trauma occurred before or after death, even if cervical spine fracture is identified on CT scans [9]. Here, MRI scans are potentially superior to CT scans, because MRI scans may depict edema and hematomas, and further studies are necessary to clarify this point. Another issue is that atlantoaxial rotatory fixation is sometimes over-diagnosed due to abnormal body positions arising from rigor mortis [10].

Discussion

The usefulness of postmortem MRI scans has been reported for cervical spine injuries [7][10][12]. However, very few institutions in Japan can perform postmortem MRI scanning. When it is necessary to perform investigations using postmortem CT scans only, it is important to take great care in evaluating these images. In cases of suspected cervical spine injuries, multiplanar images reconstructed from high-resolution CT scans are used to identify possible cervical fracture lines, deformation, and ossicles. The mechanism of trauma can be inferred based on the distribution of fractures and the presence of dislocations; therefore, it is important to assume that injuries to the upper cervical spinal cord could have been the cause of a fatality. Because there may be "spinal cord injuries without radiographic abnormalities", it is necessary to seek to identify surrounding hematomas and swelling of the soft tissue as well as fractures and dislocations, as these findings will assist in determining the mechanism of the trauma. Common and possible types of cervical spine injuries and pathologies, which must be differentiated, are listed below.

Common types of cervical spine injuries

- At the craniovertebral junction (C1–2)
- Atlantooccipital dislocations
- Fractures of the atlas (posterior arch fractures, fractures of lateral masses of the atlas, Jefferson fractures)
- Axis fractures (odontoid fractures, Hangman's fractures, extension tear-drop fractures)
- Atlantoaxial subluxation
- Atlantoaxial rotatory fixations
- At the lower cervical spine (C5–7)

- Hyperflexion injuries (ligament injuries, compression fractures, flexion tear-drop fractures, bilateral locked facets, clay-shoveler's fractures)
- Hyperflexion rotator injuries (unilateral locked facets)
- Hyperextension injuries (extension tear-drop fractures, retrospondylolisthesis, endplate avulsion fractures and intervertebral enlargement, anterior vertebral soft tissue swellings)

Pathologies to be differentiated from cervical spine injuries

Normal variations (including os odontoideum), congenital anomalies (including spina bifida, assimilation vertebra), spur formation/transformations due to cervical spondylosis, ossification of the posterior longitudinal ligament

Key words

Postmortem, CT, MRI, cervical spine

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Figure

Cervical spine injury (1)
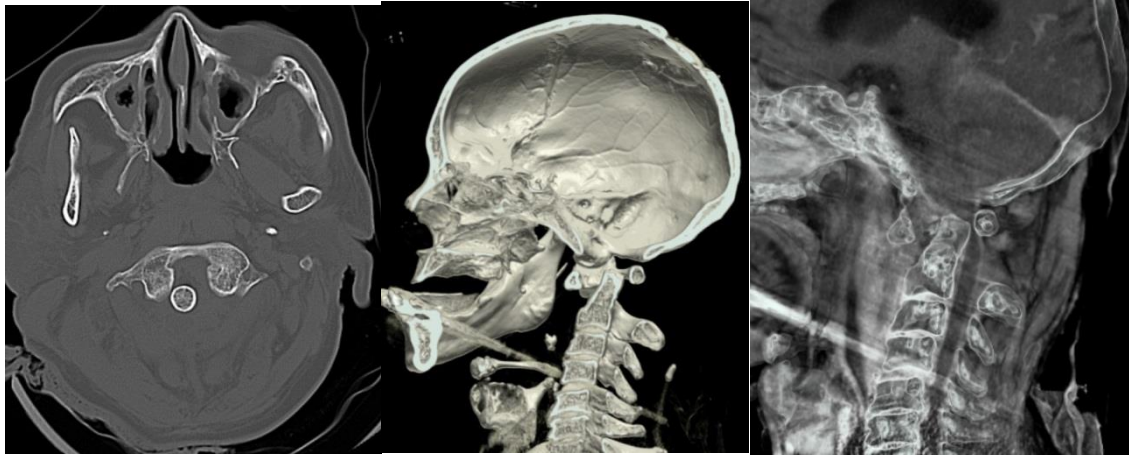
The individual was discovered after being crushed by a tractor; however, there was no compression injuries to the trunk, and no obvious trauma to the surface of the body.

The axial CT image (A) depicts dislocation of the atlantoaxial joint. Sagittal images (B, C) indicate cervical spinal cord injuries due to compression by the dens axis.

Figure

cervical spine injury (2)
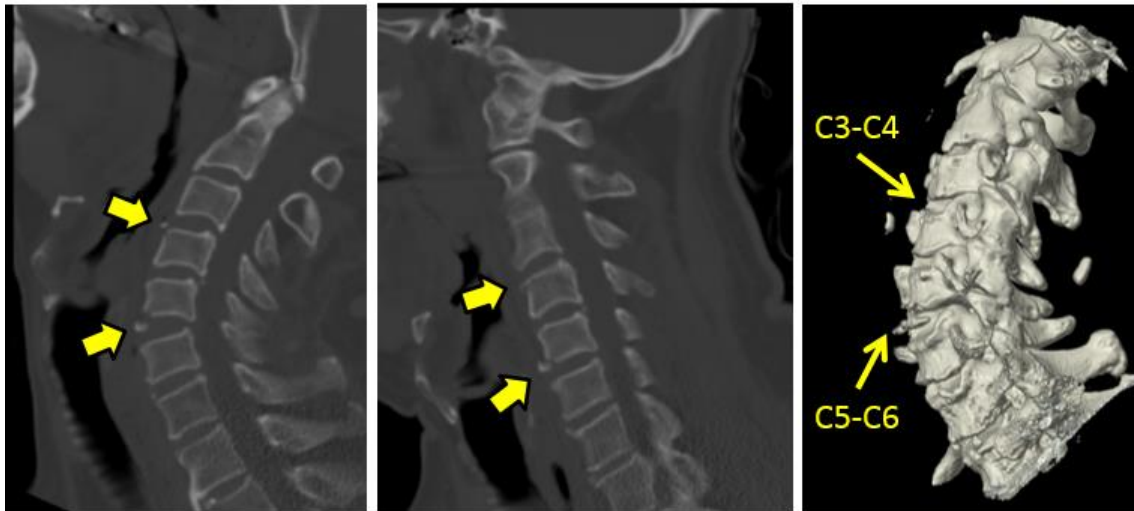
The individual was discovered leaning over a fence, with cervical overextension. The autopsy showed no abnormal posture or apparent external trauma. The CT scanning was performed with the neck in flexion (A) and extension (B). The sagittal images depict a small bone fragment at the upper levels of C4 and C6 (▲). The anterior C5-6 intervertebral space is wide open in the extension position. It is difficult to tell whether there is surrounding hematomas. A 3D reconstruction (C) depicts the fragmented ossicles (▲) but details are unclear.

Figure

cervical spine and spinal cord injury
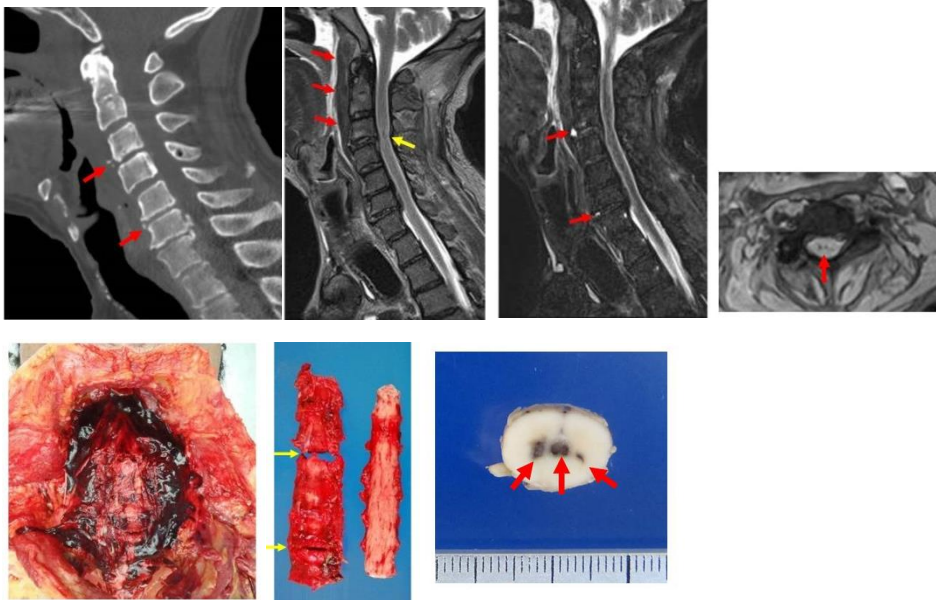
Apparently this individual had rolled down stairs from the second floor. There was a contused laceration on the forehead.

Injury to the intervertebral disks and spinal cord cannot be evaluated on the sagittal CT scan of the cervical spine, although small ossicles (▲) can be identified ventrally at the C3-4 and C5-6 levels (A). The MRI scan of the cervical spine (sagittal T2 weighted image) shows hematomas (▲) and spinal cord injuries at the level of C3-4 (→) (B). The sagittal fat-suppressed T2 weighted image depicts two high-intensity lesions (isointense to cerebrospinal fluid) at the anterior border of the intervertebral disks at the C3-4 and C6-7 levels (▲), suggestive of intervertebral disk injuries (C). The axial T2* weighted image shows patchy areas of low intensity in the spinal cord at the level of C3-4, suggestive of hematomas (D). The photograph shows hematomas anterior to the cervical spine during dissection of the cervical trachea (E). There are enlarged intervertebral spaces (▲) at the C3-4 and C6-7 levels (F). Ecchymosis is identified in the central gray matter at the level of C3-4 on an axial slice after fixation of the cervical spinal cord (G).

CQ9 Can unenhanced postmortem CT scans help diagnose an acute coronary syndrome as a cause of death?

Grade of recommendation: D

Unenhanced postmortem CT scans cannot delineate thromboembolisms of the coronary artery or ischemic myocardium; therefore, it cannot provide definitive information to diagnose acute myocardial infarction or ischemic sudden cardiac death.

Explanation

Acute coronary syndrome

The term "acute coronary syndrome" comprehensively includes three pathologic states: unstable angina, acute myocardial infarction, and ischemic sudden cardiac death. Sudden cardiac death refers to sudden death due to cardiac diseases and involves acute myocardial infarction, fatal arrhythmia, cardiomyopathy, cardiac sarcoidosis, myocarditis, and others.

Unenhanced postmortem CT scans

In clinical practice, modalities to diagnose angina, myocardial infarction, and arrhythmia include ECG, ultrasound, coronary angiography, enhanced CT scans, cardiac MRI images (with or without contrast media), and cardiac nuclear imaging. However, after death, these modalities are not practical or at least not part of standard methods [1-6]. In Japan, unenhanced postmortem CT scans are commonly used in screening examinations to determine causes of unusual death [3-6]. However, unenhanced postmortem CT scans cannot identify direct findings of acute myocardial infarctions or ischemic sudden cardiac death cases (such as coronary arterial thromboembolism and ischemic myocardium), although they can assist in detecting fatal hemorrhagic lesions (such as cerebral hemorrhages, subarachnoid hemorrhages, aortic dissections, or aortic aneurysmal ruptures) [1-6].

Pulmonary edema on postmortem CT scans

Ischemic heart disease is suspected in patients who are transferred to emergency hospitals in a state of cardiopulmonary arrest on arrival and confirmed dead after undergoing cardiopulmonary resuscitation, in combination with clinical information (such as acute chest pain before death), the patient's past medical history (such as

diagnosed with angina or old myocardial infarctions), examination findings (such as abnormal ECG findings), and indirect postmortem CT findings (such as pulmonary edema, calcification of the coronary artery, or a markedly enlarged / hypertrophic heart) [3-5]. In such sudden death cases with known clinical histories that lead to death, the presence of pulmonary edema due to acute left heart failure can be an indirect image finding of ischemic heart disease. However, pulmonary edema is a non-specific finding that may occur due to extrinsic factors (such as drugs or suffocation), and it would be difficult to differentiate it from similar CT scan densities other than pulmonary edema (such as infiltrative shadows due to pneumonia), and pulmonary edema occurring immediately before death may be masked by postmortem pulmonary edema that appears with time after death [7,8]. Therefore, the presence of pulmonary edema should not be simply interpreted as the presence of ischemic heart disease in cases where the circumstances at the time of death or the clinical history that lead to death is unknown.

On postmortem CT images, band-like shadows are often seen along the pleura in the dependent portion of the lungs. This is the so-called postmortem hypostasis of the lung [3]. It appears on the dorsal side of the body if lying / laid in the supine position after death, while it appears on the ventral side if lying in the prone position after death.

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CQ10 What are the best modalities for and acceptable findings to detect acute coronary syndrome on postmortem images?

Grade of recommendation: C2

Postmortem CT angiography (CTA) of the coronary artery has been reported to show coronary arterial thromboembolisms as a filling defect, which cannot be delineated by unenhanced CT scans. Postmortem cardiac MRI scanning has been reported to show ischemic myocardium as abnormal signal intensities, which also cannot be delineated by unenhanced CT scans.

Explanation

Acute coronary syndrome (Refer to CQ9)

The term "acute coronary syndrome" comprises three pathologic states that occur due to sudden stenosis of the coronary artery: unstable angina, acute myocardial infarction, and ischemic sudden cardiac death [1]. Unenhanced postmortem CT scans cannot directly show findings of acute myocardial infarction or ischemic sudden cardiac death cases (including coronary arterial thromboembolism and ischemic myocardium). Postmortem CTA of the coronary artery and cardiac MRI scans have been reported to show these pathologic states [2,3].

Postmortem CTA of the coronary artery

Postmortem CTA of the coronary artery is performed mainly to detect thromboembolisms. Three different methods have been reported:

Method of the Virtopsy Group in Europe [4,5]:

Based on an embalming technique, cannulation is performed in the femoral artery and femoral vein, contrast media are infused from the artery, and blood is collected from the vein to generate circulation using an artificial heart lung apparatus. Angiographic images of the entire body including the coronary artery can be obtained in this manner. Surgical techniques are required in such cases.

Method of the University of Leicester, England [6]

A urethral balloon catheter is inserted from the internal carotid artery, and the balloon is inflated at the proximal portion of the ascending aorta; then, contrast media are infused from the catheter. This method is simpler than that of the Virtopsy Group above (1), and enhanced images of the coronary artery are obtained.

Surgical techniques are also required in such cases.

Method of the Tokyo Medical Center [7]

Chest compression is performed while infusing contrast media via the peripheral venous route which is retained at the time of cardiopulmonary resuscitation in an emergency room. This method is simpler than those of the Virtopsy Group (1) and the University of Leicester (2), and no surgical techniques are mandatory; however, the ability to show the coronary artery is generally inferior to those of the other two methods.

Cardiac MRI

Postmortem cardiac MRI is conducted for the purpose of identifying ischemic myocardium. Pathological alterations due to myocardial infarction appears microscopically a few hours after the onset of myocardial infarction, and macroscopically at 6 to 12 hours. A pathological diagnosis is very difficult in ischemic sudden cardiac cases of death within a few minutes to one hour after the onset of the disease. A postmortem cardiac MRI scan can differentiate ischemic myocardium of the hyperacute phase from the acute phase, the subacute phase, and the chronic phase. With T2-weighted images on the postmortem cardiac MRI ischemic myocardium of the hyperacute phase is delineated as a low signal intensity area [7]. The reasons for the low signal intensity are considered to be due to acidosis of the ischemic myocardium or reduced arterial blood flow while venous circulation is still maintained. Approximately 3 hours after coronary artery occlusion, myocardial edema appears due to ischemia and re-perfusion injuries. Here, ischemic myocardium of the acute phase is delineated as a high signal intensity area on T2-weighted images (Figure) [8-10].

Note that when examining the heart by MRI, scan sequences should be determined to optimize scans of the heart, not for the entire chest region.
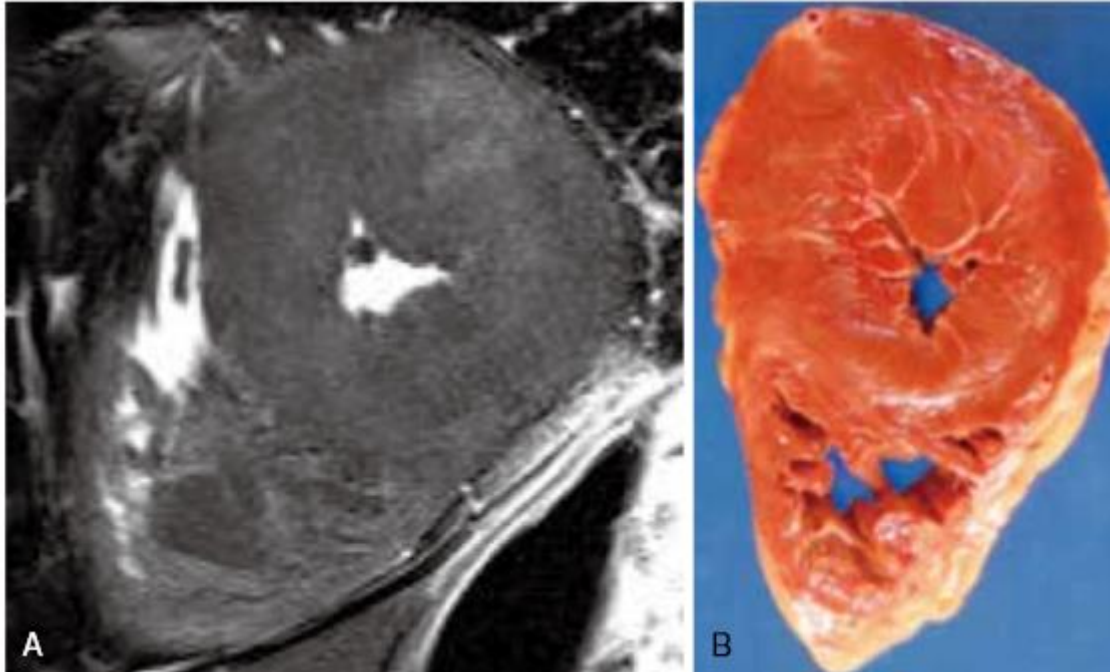
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Figure

A case of suspected catecholamine cardiomyopathy due to burn injuries of the whole body.

This individual died after severe burn injuries. On the postmortem cardiac MRI (short axis T2-weighted image at the level of the midventricular level, A), mottled high signal intensities can be seen in the entire circumference of the left ventricle. This high signal intensity extends to the right ventricular wall. The macroscopic view of a coronal section of the heart (B) shows scattered whitish-colored portions (which histologically correspond to fibrosis) in the left ventricular wall, but no lesions that correspond to the mottled high signal intensities on the MRI can be identified.

CQ11 Can postmortem CT scans be used to diagnose pericardial hematomas?

Grades of recommendations: C1 for evaluating the condition
C2 for determining the cause of death

Pericardial hematomas can be diagnosed as the cause of death when a high density band is surrounding the myocardium at the pericardium. More than 200 ml of a pericardial hematoma may be considered to be a cause of death. Postmortem procedures, such as cardiopulmonary resuscitation, cardiac centesis, may affect postmortem pericardial hemorrhages.

Explanation

Discussion

A pericardial hematoma is the condition of hematomas of the surrounding pericardial space. When the pericardial space contains material, the pericardial space pressure increases, cardiac dilatation becomes constrained, and cardiac failure may occur. This is the so-called cardiac tamponade.

Cardiac tamponade may occur for a number of reasons, due to contained serum fluid (from cardiac failure), fibrosis (infection, connective tissue diseases, uremia), and hematomas (malignancies, infections, some cause of basic bleeding, trauma, for idiopathic reasons) at the pericardial space.

A pericardial hematoma is thought to rupture from the aortic wall or myocardial wall into the pericardial lumen, which causes blood to leak into the pericardium. The pericardial hematoma restricts the cardiac atrial / ventricular motion, and increases the pericardial pressure above that in the cardiac dilatation phase, resulting in circulatory malfunction leading to death.

Pericardial hematoma image

According to published data, more than 200 ml of pericardial hematoma is likely to lead to circulatory failure, and this may further develop to become the cause of death. When the growth of a pericardial hematoma is rapid, less than 100 ml of pericardial hematoma may cause death. According to autopsy reports, pericardial hematomas have reached 300 – 400 ml or more. When the physician makes a cause of death diagnosis, the pericardial hematoma volume should not be used as a sole reason.

Shiotani et al. reported that a 60 % acute aortic dissection case collection presented

a pericardial high density area (blood cells) with a relatively lower density area (blood plasma), and the appearance of pericardial hematomas has been termed "hyperdense armored heart (HAH)". At HAH the cardiac beat continued during the bleeding into the pericardial space, and the blood in the inner pericardial space caused fibrinization (outer pericardial space blood showed de-fibrinization), so that the pericardial hematoma restricted the cardiac motion leading to this being the cause of death. In animal experiments, a pericardial hematoma could not be demonstrated in a sudden death model. When the pericardial hematoma is present in postmortem CT scans, it may be difficult to distinguish the pericardial hematoma or pericardial blood contained; when the blood leakage started before the ante-mortem period, this may show it to be a real pericardial hematoma; however, when the blood leakage started after the post-mortem period, it may indicate leakage of the postmortem liquefied blood into the pericardium. Distinguishing between pericardial hematomas and pericardial blood by the appearance of leaked blood on postmortem CT scans may be difficult.

Other findings about pericardial hematomas (cardiac tamponade) have reported venous dilatation (IVC, hepatic vein, renal vein), decreasing cardiac anterior-posterior distance, and cardiac septal deviation. When findings like those are identified along with the HAH, the cause of death may be cardiac hemo-tamponade (hematoma).

The pericardial volume measurement shows a high correlation with actual measurements (CQ23).

Differential diagnosis

1. Cardiac rupture due to myocardial infarction

2. Dissecting aortic aneurysm pericardial space rupture

3. Cardiovascular rupture due to trauma

4. Cardiovascular rupture due to CPR

5. Blood leakage due to postmortem needle insertion

6. Rare pathologies; myocarditis, coronary artery aneurysm, pulmonary artery dissection, iatorogenic (IR procedure)

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Figure

Hemo-cardiac tamponade due to dissecting aneurysmal rupture
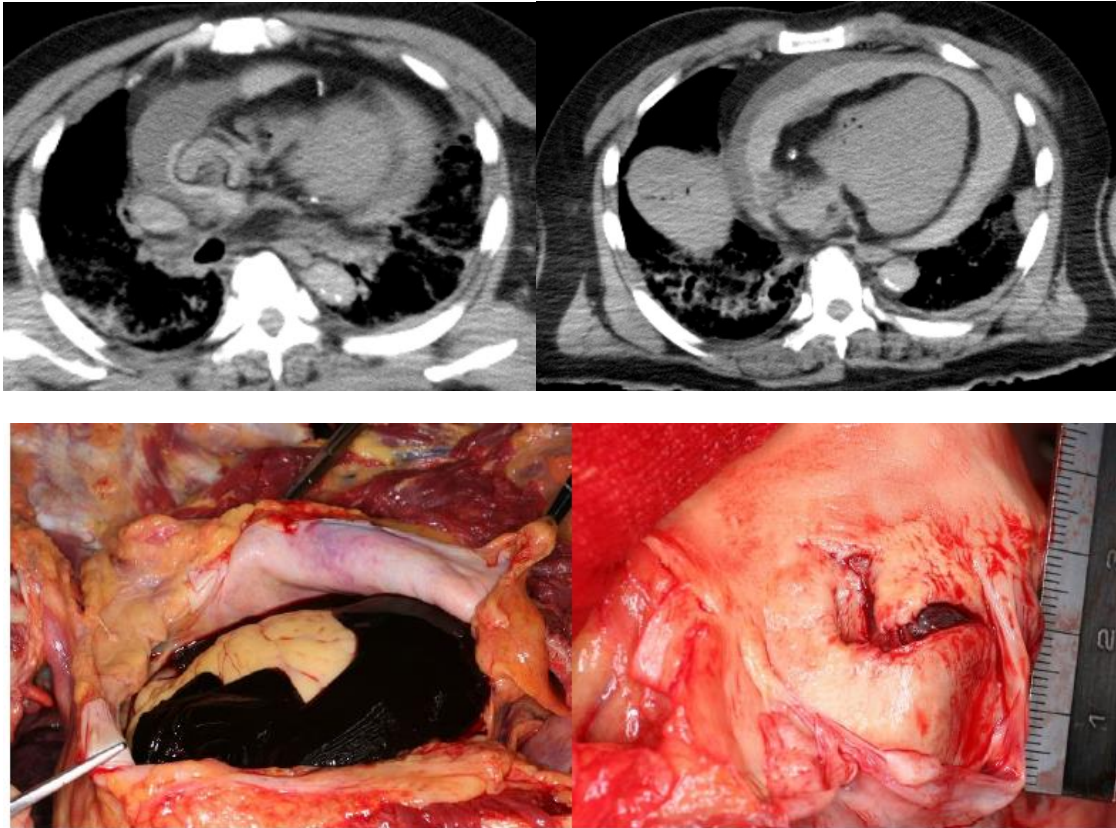
The cadaver was discovered in the driver seat. There is no motor vehicle damage.

On the postmortem CT scan, there is a double band hemo-pericardium with collapsing ascending aorta. The amount of hemo-pericardium is about 425 ml by CT volumetry. At the autopsy, pericardial coagulation is demonstrated which surrounding myocardium (the so called "armored heart"). An internal tear is detected at the ascending aorta. The cause of death was reported to be of the DeBakey type II, and aortic dissection led to pericardial rupture causing the hemo-pericardium.

Figure

Myocardial infraction, pericardial hematoma due to anterior wall rupture
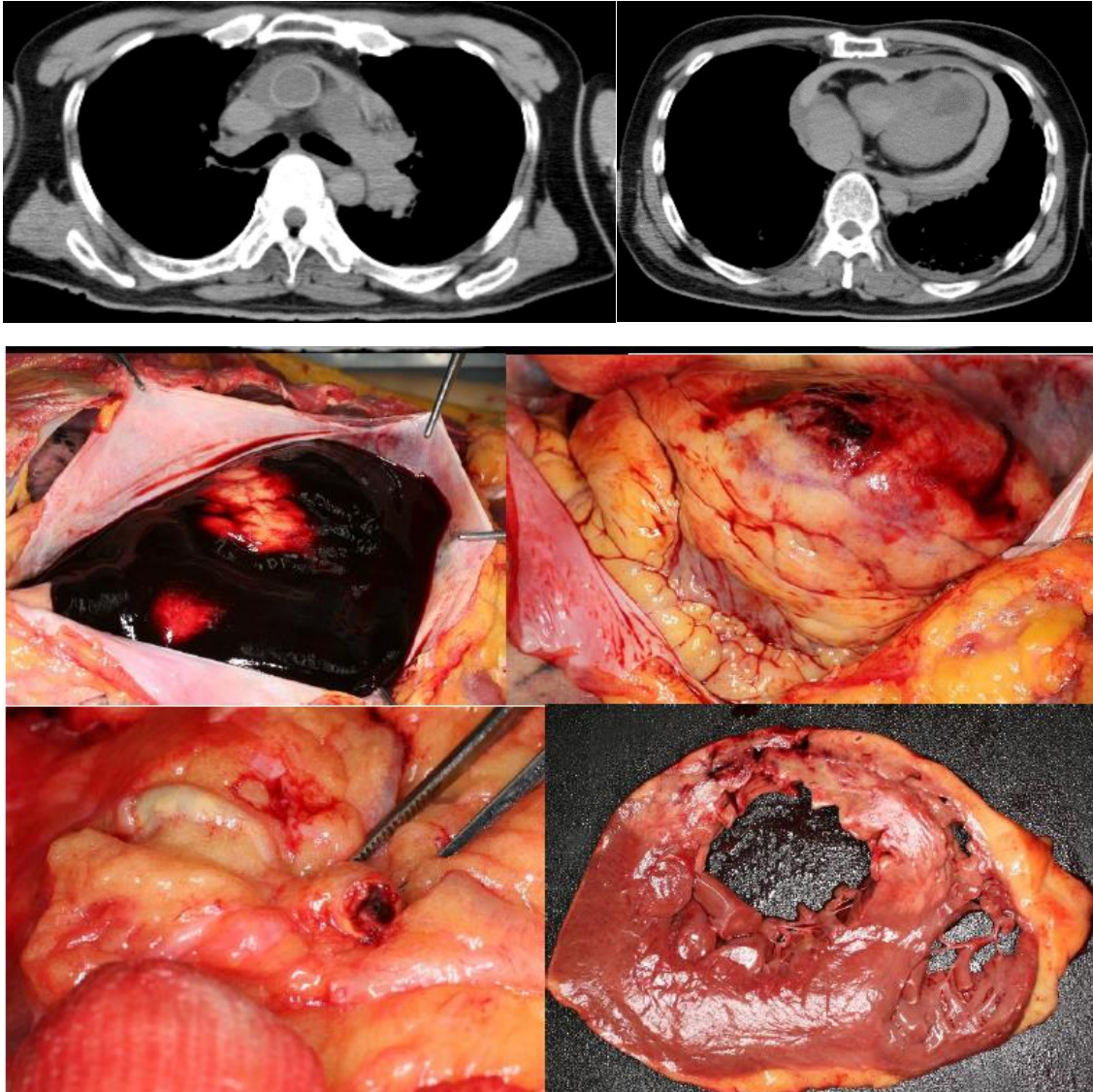
The cadaver was discovered on the sidewalk of a road. After ER admission, death was confirmed. Superficial abrasions were found at the face and fingers. The postmortem CT presented pericardial high and low density areas, with a total volume of 398.0 ml. A pericardial hematoma surrounding the myocardium, was confirmed at the autopsy. The left ventricular anterior wall presented discoloration and dehiscence. The left coronary artery was occluded at the origin of the left anterior, descending. A myocardial infarction was demonstrated at the left anterior to the septal wall with thinning and dehiscence.

CQ12 Can postmortem CT scans detect subarachnoid hemorrhages as a cause of death?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

A fatal subarachnoid hemorrhage is strongly suggested when postmortem CT scans show a subarachnoid hemorrhage concentrated at the base of the brain, accompanying intraventricular hemorrhage, or accompanying lung edema.

Explanation

Usefulness of CT scans in the detection of subarachnoid hemorrhages [1-5]

The usefulness of CT scans in the detection of subarachnoid hemorrhages has been clinically established. On unenhanced CT images, a subarachnoid hemorrhage is delineated as a high-density area in the subarachnoid space or cistern; this makes detection straightforward (Figure 1).

Scanning conditions of postmortem CT images to detect intracranial lesions [6]

The conventional CT scan mode has been reported to be better for the detection of intracranial lesions than the helical scan mode in postmortem CT scanning. Conventional scanning parameters with a slice thickness of 5 mm are considered suitable for acquiring postmortem CT images of the head region.

Comparison between postmortem CT scans and autopsy findings of subarachnoid hemorrhages [7-11]

Subarachnoid hemorrhages on postmortem CT scans has been reported to be pathologically confirmed by autopsies in radiologic-pathologic correlation studies (Figure 2).

Characteristic findings in subarachnoid hemorrhage cases involving death before arrival at a hospital [12-14]

About 3 to 17% of subarachnoid hemorrhage patients die before arriving at a hospital. Frequently observed findings in such cases include intraventricular hemorrhage, pulmonary edema, and aneurysmal rupture of the vertebrobasilar artery. Therefore, subarachnoid hemorrhage is strongly suggested as a cause of death when postmortem CT scans show a subarachnoid hemorrhage concentrated

at the base of the brain, accompanying intraventricular hemorrhage, or lung edema.

Differentiation of traumatic and non-traumatic subarachnoid hemorrhages [15-21]

In most cases, it is clinically possible to differentiate traumatic from non-traumatic subarachnoid hemorrhages associated with the rupture of an aneurysm based on CT findings of the distribution of hematomas or cerebral contusion due to a traumatic injury. However, careful diagnosis should be performed, as exceptions have been reported.

Note that differentiation between traumatic and non-traumatic subarachnoid hemorrhages is difficult in cases of head or neck injuries including mild injuries involving damage to the vertebral or basilar artery (such as from sports activity-related injuries accompanying contusions to the face, jaw, or neck, and torsion of the neck), which induces a widespread subarachnoid hemorrhage in the basal cistern.

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Figure
Traumatic subarachnoid hemorrhage
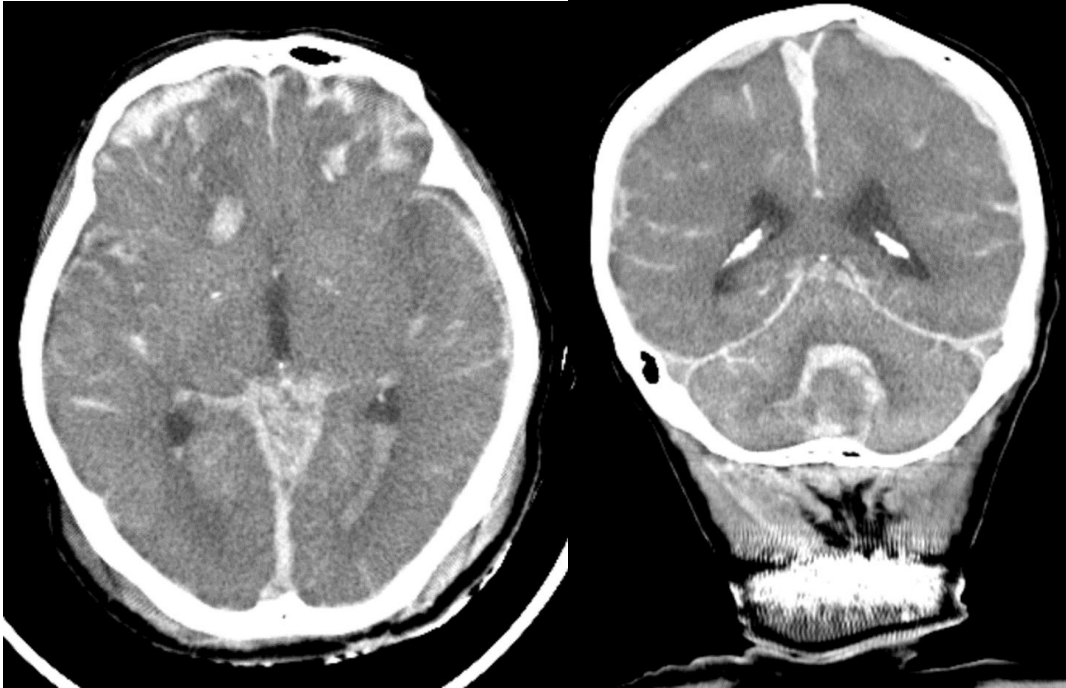
Axial (A) and coronal (B) postmortem CT images of the head.
Subdural hematoma, cerebral contusion of the frontal lobe, and secondary subcortical hemorrhage can be seen, in addition to the subarachnoid hemorrhage. A high-density fluid level is seen in the posterior horns of the bilateral ventriculi. A subgaleal hematoma (arrowhead) is visible in the left occipital region. The autopsy confirmed intracranial injuries due to the occipital region being hit (subdural hematoma, cerebral contusion, and traumatic subarachnoid hemorrhage).

Figure
Subarachnoid hemorrhage due to aneurysmal rupture of the right vertebral artery
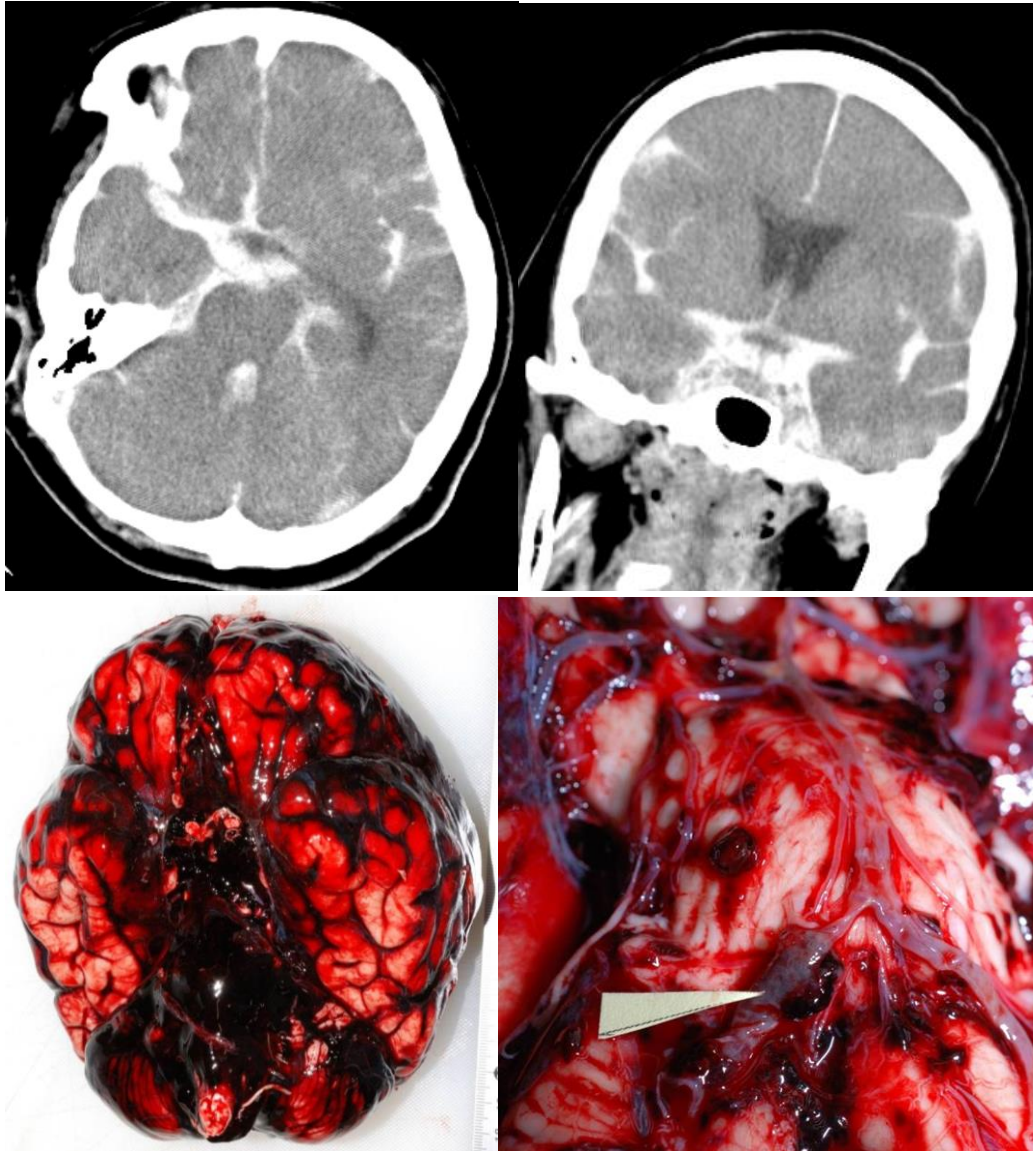
A woman living by herself was discovered dead at home. Upon superficial inspection, discoloration of the left forehead indicating old subcutaneous bleeding and hematoma of the left eyelid (black eye) were observed; an autopsy was performed for further investigation. The postmortem CT scans (axial image A, coronal image B) showed a widespread subarachnoid hemorrhage predominantly at the base of the brain. A thick hematoma is seen at the base of the resected brain (C). After removing the hematoma and exposing the artery at the base of the brain (D), a spindle-shaped aneurysm with an osculum was discovered in the right vertebral artery, this would accompany the formation of a thrombus, histologically.

CQ13 Is it possible to diagnose cerebral hemorrhages which are causes of death?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

Some hematomas, which are located in the brainstem, with volumes larger than 30 cm3, with ventricular extension of blood, with ventricle compression, or with midline shifts over 5 mm, may be strongly suspected as causes of death.

Explanation

Intracranial hemorrhages show high density on head CT scans, and it is clinically acceptable to diagnose intracranial hemorrhage.

Postmortem head CT scan parameters

Daly et al. reported that conventional CT scans are more sensitive to major intracranial findings than helical CT scans in decedents. Conventional head CT scanning is suitable for evaluating postmortem examinations.

Postmortem CT scans and pathological correlation with cerebral hemorrhages

Some investigators reported cerebral hemorrhages that were diagnosed by postmortem CT scans and which were confirmed by an autopsy. Kasahara et al. reported that six fatal cerebral hemorrhages present on postmortem CT scans were confirmed in the autopsy.

Clinical fatal findings of cerebral hemorrhages on CT scans

It is reported that predictors on head CT scans of 30-day mortality rates after the onset of intracerebral hemorrhages are 1) hematomas located in the brainstem, 2) hematoma volumes larger than 30 cm3, 3) ventricular extension of blood, 4) ventricle compression by a hematoma, or 5) hematomas with midline shifts of more than 5mm. Such life-threatening findings are strongly suspected as causes of death.

#: Subtle cranial fractures are difficult to detect on CT images. Postmortem destruction should be taken into consideration.

Reference

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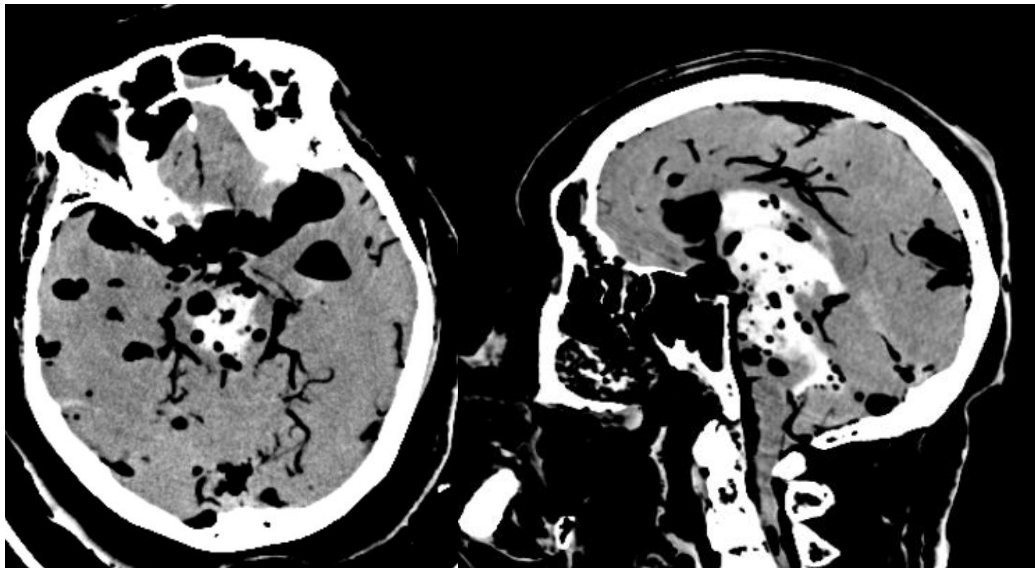
Figure

Brainstem bleeding (postmortem about 1 month)

Because of putrefaction, air (gas) is demonstrated in the brain parenchyma. There is a high density at the brainstem, making the cause of death estimated to be brainstem bleeding.

Figure

Right thalamic bleeding (confirmed by autopsy)

The brain CT scan (fig. a) presented intra-cranial bleeding which penetrates into the lateral ventricle, so that a fluid-fluid level is present at both the posterior horns of the lateral ventricles. The bleeding (hematoma) volume was measured as 80.6 ml on the image workstation, and 104.2 ml with intra-ventricular bleeding (high density volume).

Chest CT scan (fig. b) showing ground-glass opacity with bilateral pleural space fluid collection. At the autopsy, the lung weight was 586 g for the left lung and 716 g for the right lung. At the macroscopic investigation, the lung showed severe edematous changes. The pleural space fluid collection is about 40 ml in the left chest cavity and about 50 ml in the right chest cavity. Because the cadaver was discovered at low temperature circumstances, the putrefaction changes were minimized. The postmortem interval was estimated to be about 7 days.

CQ14 Can aortic aneurysms and aortic dissections be diagnosed as the cause of death by postmortem imaging?

Grades of recommendations: C1 for evaluating the condition
C2 for determining the cause of death

Aortic ruptures caused by aortic dissection and ruptures of aortic aneurysms may be a cause of death by inducing hemorrhagic shock and may be diagnosed by postmortem imaging.

Diagnosis of the direct cause of death is straightforward if there is only one pathological condition.

However, if the condition is caused by an injury, the severity of other findings should also be assessed.

Explanation

Aortic dissection is a condition in which the inner layer of the aorta is torn and blood surges through the tear, causing the inner and middle layers of the aorta to separate.

A Stanford A type with the lesion of the ascending aorta may be fatal if it is treated conservatively: 20% of patients die within 24 hours of the onset, 30% within 48 hours, 40% within 1 week and 50% die within 1 month. Most of the deaths are due to cardiac tamponade arising from the development of the hemorrhage into pericardial space. [1-8]

Some reports have found postmortem CT scans with enhancement useful to diagnose the condition.

What findings may be identified?

The evidence of a fatal hemorrhagic lesion are: ① High-attenuation fluid collection surrounding the aorta (a hematoma) [1-8], ② a pericardial hematoma[7], ③ mural thrombosis, depiction of a false lumen, ④hemorrhagic pleural effusion, ascites, ⑤ deformity of the arterial wall, deformed aneurysms, and ⑥ rupture of aortic aneurysm wall.

What findings may be evidence for the cause of death?

One of the six described above may be evidence.

However, a single finding of pericardial hemorrhage is sometimes difficult to differentiate from a left ventricular rupture caused by myocardial infarction.

In other situations, hemorrhagic pleural effusion may be caused by the rupture of the pericardium after chest oppression in cases of left ventricular rupture caused by myocardial infarction[9].

Also, rupture of abdominal aortic aneurysms may cause a hemorrhage not in the abdominal cavity but in the retroperitoneum.

What kind of imaging conditions are useful to diagnose these conditions?

Reconstructed images such as sagittal images may be useful to identify sites of entry and re-entry of a dissection.

It is also useful to establish the site of the rupture.

**Pathological conditions and diseases that must be differentiated**

a) Aortic aneurysm (dissection・genuine aneurysm)

b) Traumatic aortic rupture (isthmus of the aorta)

c) Traumatic cardiac rupture and pericardium rupture (in falls from high places)

d) Multiple injuries to the thorax (lung contusion・Pneumothorax・injuries to the intercostal arteries and veins)

e) Cardiac and pericardial ruptures caused by chest oppression (cardiopulmonary resuscitation)

f) Spontaneous pneumothorax and endometriosis in rare cases

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Figure

Thoracic aortic aneurysm rupture
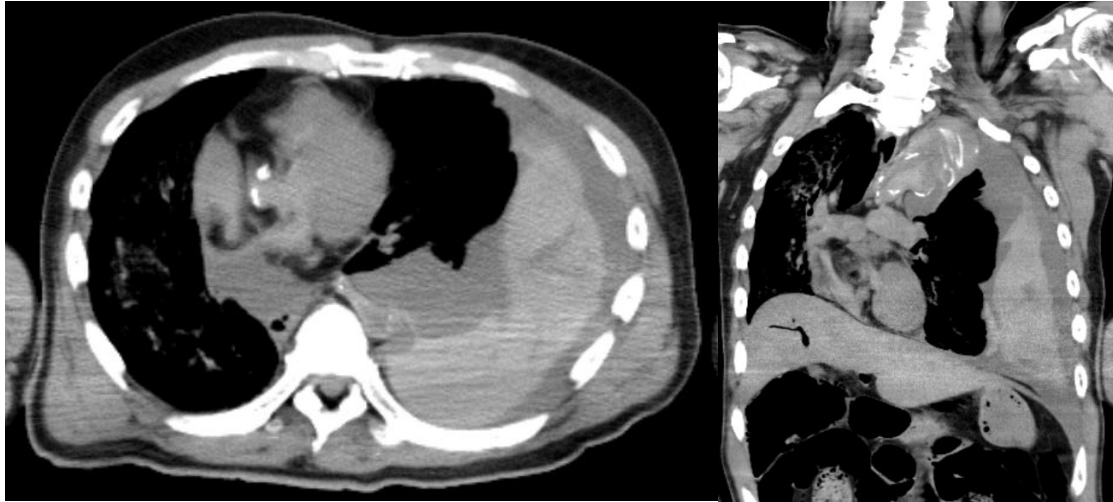
The crescent shaped high density which is surrounded by an iso-density present at the left pleural space. The high density is estimated to be coagulated blood. The mediastinum right side shift is also marked. Using MPR imaging, it is helpful to assume the lesion distribution. Thoracic aortic dilatation is present at the aortic arch with irregular calcification, but the exact rupture point is difficult to determine.

Figure

Abdominal aortic aneurysm rupture
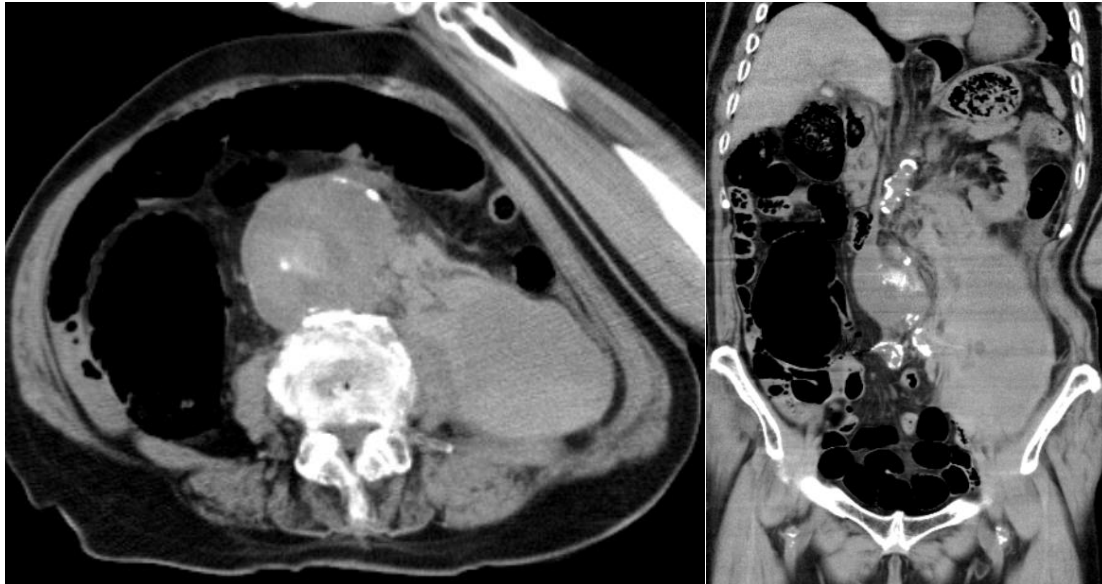
An abdominal aortic aneurysm was reported in the past history of this person. Because of the general health condition, this lesion did not admit of surgical intervention and was kept under observation without hospitalization. The patient was discovered on the dressing room floor. This postmortem CT scan presents the abdominal aortic aneurysm with a retroperitoneal high-density, and it is expected as showing abdominal aortic rupture and retroperitoneal hemorrhage.

CQ15 What are useful findings of postmortem imaging in the diagnosis of drowning? Is postmortem imaging useful to differentiate pulmonary edema caused by drowning from the edema caused by acute cardiac failure?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

Water in the paranasal sinuses and the mastoid air cells, fluid collection and high-attenuation sediment in the airways, ground-glass opacity within the lungs, pleural effusion, and gastric extension are considered valuable, frequent findings suggesting drowning.

However, these findings are not specific to drowning. Therefore, a differential diagnosis is difficult.

Explanation

Drowning

Drowning is the result of a hampering of respiration by obstruction of airways by a fluid medium. Therefore, it is classified as suffocation.

Though the mechanism of drowning in fresh or seawater is different, factors such as changes in circulation volume and hemolysis caused by drowning, fatal arrhythmia caused by electrolyte abnormalities, and circulatory insufficiency caused by cardiac pump failure are considered to contribute to the cause of death.

The crucial point in investigations of bodies recovered out of water is whether the victim died due to 'true' drowning or by immersion death. However, autopsy techniques also find this differentiation difficult[1].

A white plume of froth found in the airways from the mouth and nostrils to the bronchi, lung emphysema and edema aquosum, aqueous pulmonary edema in the split surface, fluid collection in the thoracic cavity caused by postmortem leakage of aspirated fluid, and the detection of diatoms in the organs are considered valuable indications of drowning at autopsies.

However, findings of washerwoman's hand and horripilation, damage caused by aquatic animal phagocytosis and underwater movement, and cooling of the body may be caused after death. Therefore, such findings are simply indications that a corpse has been immersed in water.

Sings of drowning in Postmortem CT scans

A number of reports of Postmortem CT scan findings in drowning have reported that[2)3)] water and high-attenuation sediment in the paranasal sinuses and airways, mastoid air cell fluids, plumes of froth in the airways, ground-glass opacity within the lungs, pleural effusions, thickening of interlobular septa, and gastric extensions may be considered characteristic to drowning.[2)3)].

Levy, et al.[2)] concluded that frothy airway fluid and high-attenuation airway sediment strongly suggest drowning because such findings have only been made in cases of drowning.

Other reports [4)] found that postmortem CT scans could not detect the white frothy airway fluid which is detected by autopsies, and this finding cannot be considered definite.

Further, as high-attenuation airway sediment is a sign of sand grains in the aspirated fluid, its specificity is high but the sensitivity depends on the nature of the aspirated fluid.

Since airways, including the paranasal sinuses, are cavities open to the outside, the possibility of passive intrusion of fluid into the airways is possible and fluid identified here need not be a positive finding to indicate drowning.

As a key point to differentiate pulmonary edema caused by drowning and not by circulatory failure, Christe, et al. [3)] report that ground-glass opacity within the lungs in cases of drowning shows a characteristic 'mosaic pattern' and this would be an important point to differentiate if pulmonary edema is caused by drowning rather than caused by circulatory failure.

There are also reports that have found the proximity of the bilateral lungs in the anterior mediastinum to be a specific sign of the bulging lungs found in drowning.

Since all of these determinations are based on overall frequencies and trends without sufficient statistical analysis, these findings can only be considered supportive in a final determination of drowning.

It is important not to think that the cause of death is drowning in cases where all these characteristic findings are absent.

Reference

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Figure

Drowning
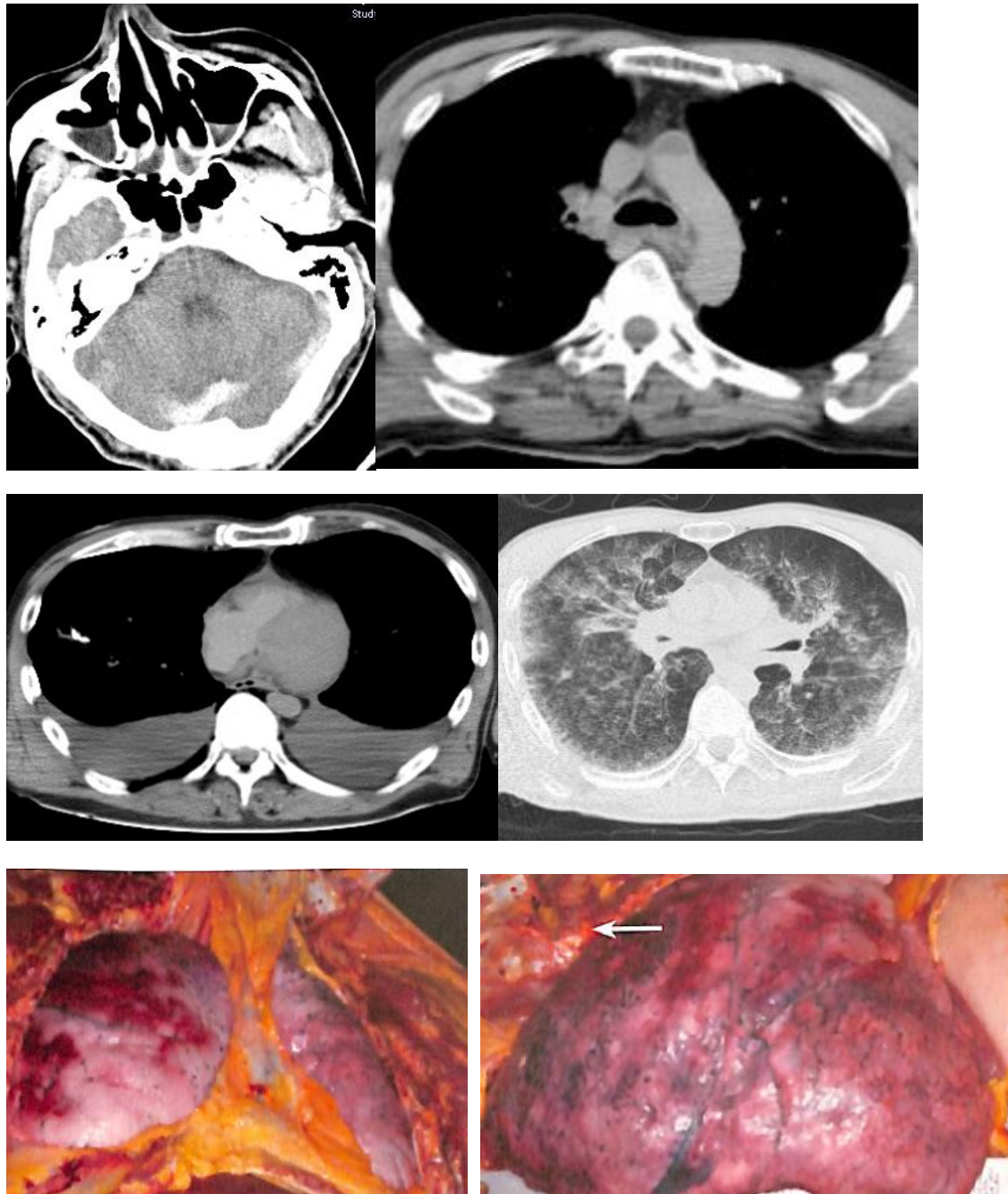
a. Maxillary sinus fluid collection
b. Fluid collected at the trachea and bronchus
c. A fluid-fluid level (horizontal sign) is present in the right atrium (arrowhead), and so the blood can be expected to be liquid. Bilateral pleural space fluid collection is demonstrated.

d. On the lung window setting, there is diffuse lung opacity, the so-called diffuse lung pattern. The hypostasis is not predominant in drowning cases.

e. At the autopsy, the lung parenchyma is expanded with edematous changes (the so-called emphysema aquosum). The anterior junction line is close.

f. The lung parenchyma presents rich aeration and a rib compression mark at the lateral surface.

CQ16 What are useful findings to determine hypothermia in postmortem imaging?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

> In postmortem CT scans, the preserved air densities in the lungs, clot formation in the cardiovascular system (cast-like high-density structures), or high-volumes of urine in the bladder, are suggestive of hypothermia.

Explanation

Background

Hypothermia is a fatal state directly causing death from fatal decreases in vitality due to low body temperature caused by exposure to cold. At autopsies, it is known that findings of hypothermia deaths may include gastric black spots of hemorrhages (Wischnewski spots), color differences between the right and left heart blood, collapsed lungs, and urine collected in the bladder. However, hypothermic deaths are difficult to diagnose solely by these findings. Consideration for why a victim was exposed to and did not escape from a cold environment must be considered. The above autopsy findings only suggest "direct causes of death" but not "original causes of death" or the "manner of death". For example, murder may be the original cause if someone on purpose has left the victim in the cold environment. If the victim developed hypothermia as a result of immobilization from diabetic coma, hepatic encephalopathy or cerebral infarctions, this could be death by these diseases.

Recently, reports published by Japanese researchers have investigated postmortem computed tomography (PMCT) findings of hypothermia, and these will be discussed in this section. However, there are further problems to be discussed before determining hypothermic death only supported by PMCT findings. At this point, it is recommended that readers must show caution when determining hypothermic deaths as mentioned above and determinations have to be made carefully, in a case-by-case manner. If there are still unknown aspects that may have been overlooked after this approach is invoked, the readers of the PMCT scans must persuade the law enforcement officers to do further investigation and autopsy.

Preservation of air-densities in the lungs

Increased densities in particular depending on the part of the lungs, so-called

"hypostasis", are usually found in postmortem imaging[1]. In hypothermic death cases, these hypostatic changes are not clearly seen, and air densities may be preserved in the lungs like antemortem images.

Hyodoh et al. reported that the proportion of lung volume with air densities (-700 to -1000HU) to lung total volume is significantly higher in hypothermic deaths than in non-hypothermic deaths, from results of a comparison of 13 cases and 118 controls[2]. Kawasumi et al. reported that increased lung densities occurred significantly less frequently in a hypothermic death group (n=24) than in a non-hypothermic death group (n=53) [3]. Michiue et al., in an examination of 135 cases including 8 hypothermic deaths, classified some groups of PMCT images using some measurements such as the mean CT scan values in axial images of the lungs and showed that hypothermic deaths belong to the group of the least increased densities[4]. In this report, deaths due to malnutrition or obstructive pulmonary diseases are also categorized into this pattern, suggesting a potential differential diagnosis.

Intravascular clot

In PMCT, high-density cast-like structures can sometimes be seen in the heart and aorta[5]. Kawasumi et al. reported that such findings are significantly more frequent in hypothermic deaths than in non-hypothermic deaths[3].

Volume of liquid in the bladder

In autopsies, it is known that the volume contained in the bladder increases in hypothermic death cases and assumed this to be caused by a longer time course prior to death. Kawasumi et al. reported that if the cutoff value was set at 67.1 ml for bladder volume, the volume is significantly higher in hypothermic deaths than non-hypothermic deaths[3].

In cases with all the 3 findings

Kawasumi et al. reported that if the 3 findings above are all in PMCT, the sensitivity and specificity for the diagnosis of hypothermia becomes 29.2% and 100% respectively[3]. The results show high diagnostic values with very high specificity, but there are still some limitations on the validity, including uncertainties in the definition of hypothermic deaths in this report. Besides, even if these findings appear on PMCT scans, the "original cause of death" and "manner of death" are still unclear and requiring a case-by-case, comprehensive diagnosis as

stated above.

*If these three findings are all identified in PMCT scans to determine the causes of death requires establishment of the origin of the hypothermia. As long as the origin is unclear, it is recommended to persuade law enforcement officers to conduct further investigation and autopsies.

Search formula・secondary references
The authors performed a search of Pubmed for the recent 10 years using combined keywords as follows; "postmortem CT" or "postmortem imaging" or "forensic radiology" or "virtual autopsy" or "virtopsy", hypothermia, and cause of death.

Reference

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Figure

Hypothermic death
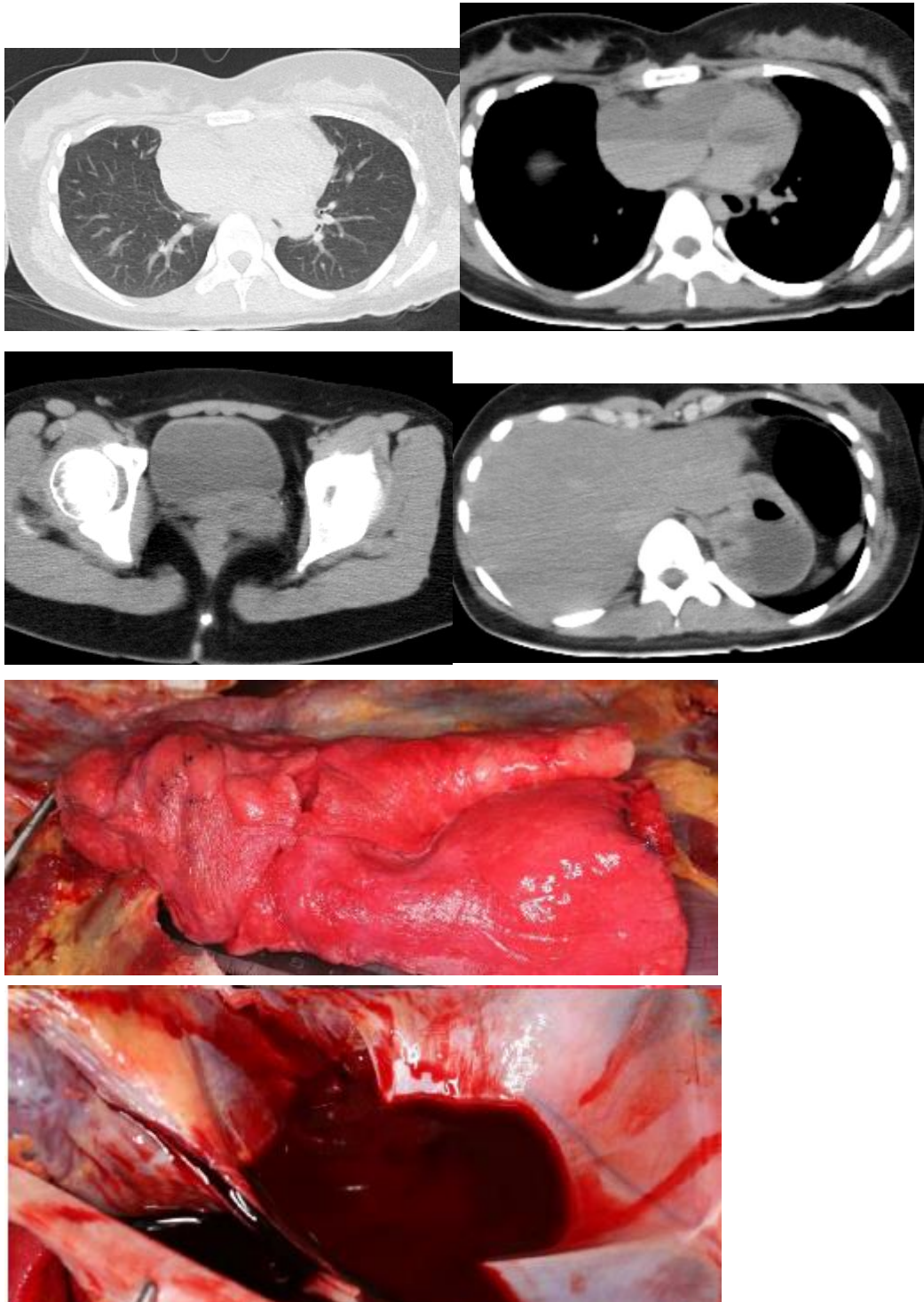
a. Postmortem lung image presenting high aeration (low hypostasis), similar to the lungs of a living person.

b. At the autopsy, the lung weight was about 112 g for the left lung and about 112 g for the right lung. Both lungs show little edematous change and bright red color, macroscopically.

c. The fluid-fluid level (horizontal line) is presented at the right atrium, and the left ventricle, so the blood is expected to be liquid. The typical blood form at hypothermic death cadavers report liquidity of the blood, and this case also presents blood in the liquid form.

d. The color difference between venous and arterial blood is also a typical finding in hypothermic deaths (cadavers).

e. The stomach contains iso-density fluid.

f. In the macroscopic investigation, the mucosal membrane shows spots including bleeding spots (so called Wischnewski spots), but it is difficult to detect these on the postmortem CT scans.

g. The urinary blood volume tends to increase in hypothermic deaths.

There is no sign of any cause of death in this case, and hypothermic death may be expected as the cause of death here.

CQ17 What findings are useful in estimating starvation while alive on postmortem CT scans?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

It is reported that emphysematous changes or hyperlucency of the lung may be identified as establishing starvation on postmortem CT scans. However, such findings are not specific to starvation. One study for patients with anorexia nervosa who are considered to be similar to the persons showing a state of starvation reported that there are findings of lung emphysematous changes, dilatation of the ventricle and sulcus, decreased orbital fat, and enophthalmos. It is known that forensic findings of death from starvation are the following: decreased subcutaneous fat, muscle atrophy, enophthalmos, or sunken intercostal space (also in the hypochondriac part or iliac part) as external findings and effusion into body cavities (pleural effusion, ascites, pericardial effusion), decreased visceral fat, collapse of the digestive tract, or enlargement of the gallbladder as internal findings. These findings are possibly helpful in interpreting postmortem images. Research studies of postmortem images of death from starvation are still too few and there is no solid evidence to decide starvation based on such images. Reference criteria for a diagnosis of death from starvation by postmortem images have not been established.

Explanation
definition of the starvation
Starvation is considered to be the state of a stoppage or lack of nutrient intake which is needed for the maintenance of life. Death from starvation is the state of being mortal resulting from exhaustion of internal energy sources. Decreased subcutaneous fat, muscle atrophy, or loss of weight of organs other than the brain is observed with severe emaciation. Edematous changes by hypoproteinemia, pleural effusion, ascites, pericardial effusion, and others can occur since protein is used for the energy source.

CT findings of starvation
Michaud et al. evaluated the relationship between cause of death and lung findings on postmortem CT scans using the CT value of lung parenchyma. They reported

that diffuse emphysematous changes and decreased vascularity of the lungs are observed in the case of death from starvation, and that the mean and mode CT value are -760 and -560 HU, respectively, reflecting the hyperlucency of the lungs [1]. However, these results are not sufficiently specific or sufficient to consider postmortem changes, and there is still room for further elucidation. To date, there are few studies about starvation and its signs on postmortem images.

External and internal findings of starvation

One study of death from hunger strikes or starvation reported that the following external findings were identified: decreased subcutaneous fat, muscle atrophy, enophthalmos (decreased orbital fat), sunken cheeks (also supraclavicular fossae, intercostal spaces, hypochondriac, or iliac parts), and decubitus ulcers on sacral areas and heels. In addition, pleural effusion, ascites, pericardial effusions, decreased visceral fat (also more omentum, mesenteric, pericaridial fat, and more), lack of digestive tract contents, enlargement of the gallbladder, or brain swelling are reported to be observed as internal findings [2,3]. These findings may help to determine starvation because forensic findings which are specific to starvation are also found on postmortem images.

CT/MR findings of starvation while alive

Coxson et al. reported that long-time malnutrition led to emphysematous changes of the lungs on CT scans in patients with anorexia nervosa [6]. This is related to a previous study by Michiue et al. which reported hyperlucency of the lungs in cases of death from starvation.

Another study of head CT scans of patients with anorexia nervosa reported that dilatation of the ventricles and sulcus, increased density of orbital or subcutaneous fat, decreased orbital fat, and enophthalmos [5]. It is also reported dilatation of the inferior horn of the lateral ventricle and sulcus, disappearance of fat signal intensity of the skull bone marrow, cranial subcutaneous tissue, and orbit on head MRI scans [6,7].

Discussion

Emphysematous changes of the lungs on postmortem CT scans may suggest a state of starvation, it is insufficient to determine death from starvation by only this finding and other information such as external findings is needed for a final evaluation.

Several studies reported significant decreases in fat, enophthalmos, and other external findings for death from starvation before the autopsy. It is reported that there are findings reflecting emaciation in patients with anorexia nervosa on CT/MRI scans and similar findings may possibly be identified on postmortem CT/MRI scans. Brain swelling as an internal finding and brain atrophy in premortem CT/MR scan findings are reported to have been observed for the state of starvation. Conflicting findings including brain swelling which is observed in autopsies is thought to be caused by "normal" postmortem changes and not necessarily due to a state of starvation.

Research methodology and supplementary materials

The following terms were used to search PubMed: postmortem, forensic, CT, computed tomography, MRI, magnetic resonance imaging, malnutrition, undernourishment, undernourished, poor nutrition, undernutrition, emaciation, starve, starving, starvation, hunger, death.

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Figure

An autopsy of a death from starvation

This female had a medical history of anorexia nervosa and living alone, and was discovered dead in her room. Height: 154 cm, Weight: 32 kg (BMI 13.85). Atrophic changes to the brain were not observed and there is no apparent sulcus (A). The heart appears small on the chest CT scan (weight of the heart: 150 g) (B). The lucency of the lungs is significantly high and there is no hypostasis in the lungs (weight of left and right lungs: 150 g and 158 g, (C). Abdominal organs and internal genitalia are atrophic (weight of the liver, spleen, pancreas, and internal genitalia (uterus and ovaries): 700 g, 36 g, 19 g and 66 g, respectively), and there is no gastrointestinal matter (D). Muscles are atrophic and subcutaneous fat is significantly poor. The autopsy showed no fatal lesions or injuries other than the findings of severe emaciation and atrophic organs.

CQ18 Is it possible to diagnose malignant neoplasms on postmortem CT scans?

Grades of recommendation: C1

Many investigators have reported that malignant neoplasms are presented as solid tumors on postmortem CT scans and that this was confirmed by autopsies. However, the origin or pathology of the tumors was difficult to determine. The usefulness of a postmortem biopsy was reported to be able to investigate the pathology. Similar findings with other diseases may be misdiagnosed as malignant neoplasms. Some infiltrated tumors cannot be identified on postmortem CT scans. It is not possible to identify all malignant neoplasms on postmortem CT scans.

Explanation
Background
Malignant neoplasms have maintained the position as most common among causes of death in Japan since 1981. They account for 28.5% of the number of deaths in 2011.

Neoplasms which can be identified on postmortem CT scans
Pulmonary tumors, tracheal tumors, pleural tumors, pharyngeal tumors, intestinal tumors, hepatic tumors, brain tumors, and adrenal tumors have been reported to have been identified on postmortem CT scans and have been confirmed by autopsies. Robert et al. reported that it was not possible to distinguish primary lung cancers from metastatic tumors or liver tumors from abscesses, which were identified on postmortem CT scans. A postmortem biopsy is useful for a histopathological diagnosis, which is necessary to make a definitive diagnosis. Robert et al. also reported that pancreatic cancers and gallbladder cancers have been misdiagnosed as duodenal cancers. It appears to be difficult to diagnose the tumor location correctly.

Neoplasms which cannot be detected on postmortem CT scans
Metastatic pulmonary tumors, colon cancers, bronchial cancers, gastric cancers, and pulmonary cancers have not been reported as detected on postmortem CT scans. Pulmonary cancers may be difficult to detect when they are not solitary, overlapping other structures, or small.
It is reported that some malignant neoplasms, including infiltrated hepatic

metastases (breast cancers, malignant lymphomas, lung cancers, prostatic cancers, renal cancers, melanomas, and neuroblastomas), pancreatic cancers, and pulmonary artery embolisms due to tumors were not detected clinically on CT scans and were only diagnosed by autopsies after death. Such tumors would not be possible to detect on postmortem CT scans.

Additional remarks

If malignant neoplasms were diagnosed before death, only some tumors can be detected on postmortem CT scans. It is necessary to show care in diagnosing tumor recurrences because some diseases show findings similar to tumor recurrences. O'Donnell et al. reported liver metastases which were clearly demonstrated on postmortem contrast CT scans. It is possible that postmortem contrast CT scan examination is useful to detect tumors.

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metastases from primary breast carcinomas: a clinicopathologic study of 3 autopsy cases. Arch Pathol Lab Med 128(12):1418-23, 2004 （levelV）

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Figure

Esophageal carcinoma
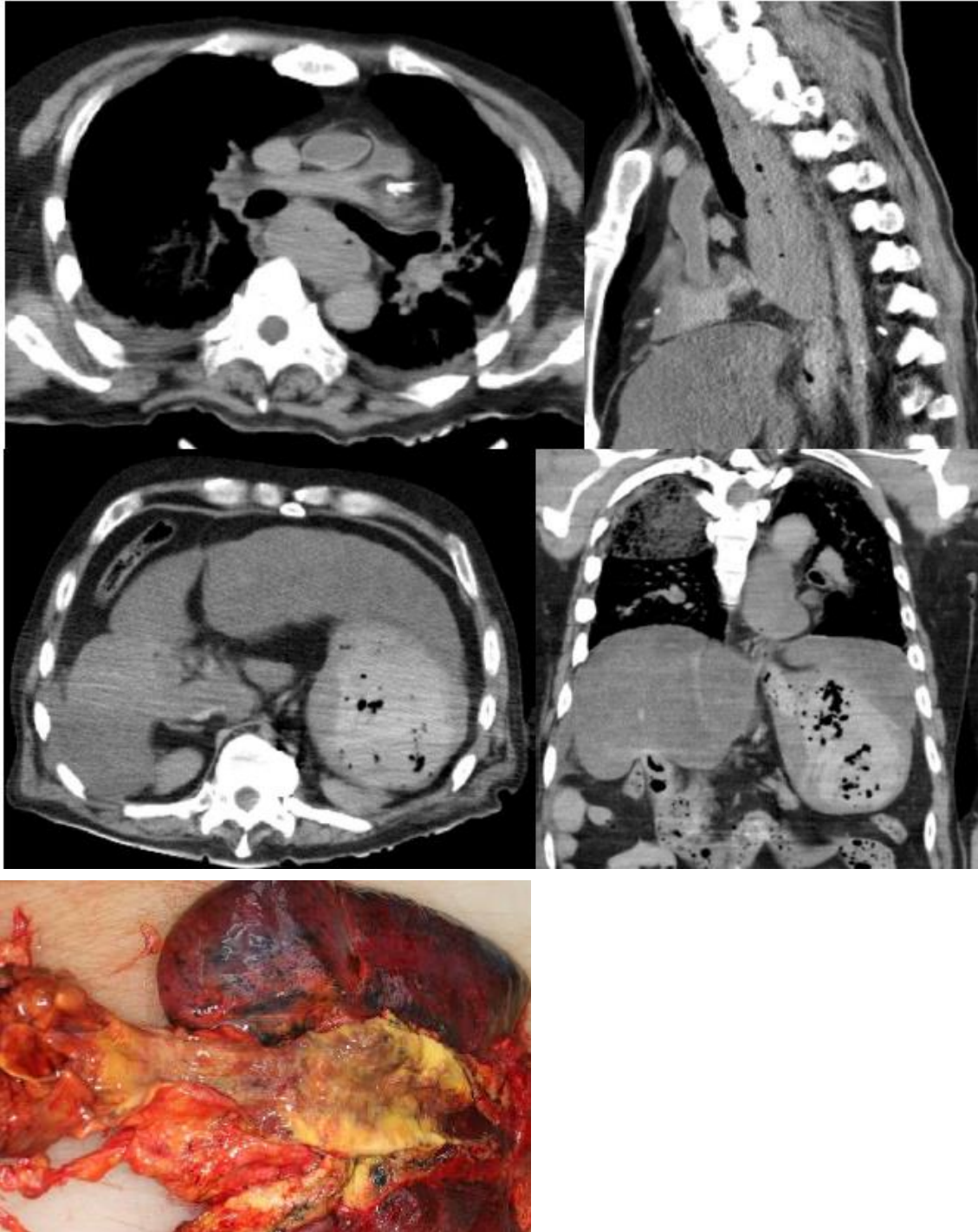
a.b.　This postmortem CT scan presents a soft tissue density mass at the thoracic esophagus.

c.d.　High density collection is clearly visible in the stomach and duodenum, and intestinal bleeding may be expected as the cause of death. The liver parenchyma

presents deformities and has a lower density than the spleen, so that liver cirrhosis with fatty changes may be expected.

e.   At the autopsy, the esophageal carcinoma with coagulation was detected. Partial tumor necrosis is also detected.

Gastrointestinal bleeding hypotension is expected as the cause of death.

CQ19 Can postmortem imaging diagnose the direct cause of death due to malignant neoplasms?

Grade of Recommendation: C2

Reported findings of lethal organic malignant neoplasms confirmed to be the direct cause of death by autopsy include respiratory failure due to severe malignant pleural effusion, liver failure due to diffuse liver metastases, heart failure due to myocardial metastasis, pulmonary artery tumor embolisms, and severe ascites due to peritoneal dissemination. Among these findings, severe pleural effusion and ascites can be detected with postmortem CT scans, but diffuse liver metastases, myocardial metastasis, and pulmonary artery tumor embolisms are difficult to detect.

Explanation

Malignant neoplasms diagnosed as the direct cause of death with postmortem CT scans

Some studies have reported that malignant neoplasms can be detected with postmortem CT scans [1-9]; however, no studies have focused on malignant neoplasms as a direct cause of death. One case report described a patient where the cause of death was diagnosed as asphyxiation due to endobronchial metastasis from a renal carcinoma with postmortem CT scans; however, the diagnosis was not confirmed by traditional autopsy [10].

Malignant neoplasms diagnosed as the direct cause of death with clinical CT scans

In clinical settings, reported cases of lethal organic malignant neoplasms as the direct causes of death include: respiratory failure due to severe malignant pleural effusion caused by pleural dissemination of breast cancer, lung cancer, ovarian cancer, and mesotheliomas [11]; liver failure due to diffuse liver metastases [12-15]; heart failure due to metastasis into myocardia and cardiac outflow tracts [16,17]; pulmonary artery tumor embolisms [18]; and severe ascites due to peritoneal dissemination of ovarian cancer [19]. As somatic cavities are easy to assess with CT scans, severe pleural effusion and ascites can be diagnosed with postmortem CT scans [8]. Diffuse liver metastases [12,13,15], myocardial metastasis, and tumor embolisms [16-18] are difficult to diagnose even with clinical (antemortem) CT scans and often cannot be detected with postmortem CT scans.

Research methodology and supplementary materials
The following terms were searched for on PubMed with parameters defined to be within the past 10 years: postmortem CT, malignancy, autopsy, causes of death. Referenced documents in the resulting articles and other useful papers have also been cited.

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CQ20 What radiological findings are useful in the diagnosis of pneumonia with postmortem CT scans?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

A previous study of postmortem CT scanning reported that segmental consolidations and multiple fused patchy consolidations were identified in cases with pneumonia. However, these findings are not specific to pneumonia. Similar findings have been reported with postmortem CT scans from patients with nonpathological postmortem changes (lung cadaveric lividity), pulmonary congestion, or pulmonary edema.

The diagnosis of pneumonia with postmortem imaging has not yet been fully investigated and there is insufficient evidence to draw final conclusions. The diagnostic criteria for pneumonia with postmortem CT scans have not yet been established.

Explanation

A previous descriptive study reported that the abovementioned findings with postmortem CT scans were observed in cases with pneumonia [1]. These findings would suggest the possibility of pneumonia. However, no radiologic–pathologic correlation was investigated in the study. Further, the study showed several limitations as follows: cases with severely damaged bodies (cadavers), chest trauma, hemothorax and pneumothorax, severe pleural effusion, and putrefaction gas were excluded; the presence or absence of laterality in lung findings were not considered; elapsed time since death was not assessed (the influence of lung cadaveric lividity as a non-pathological postmortem change [2] was not considered). Therefore, pneumonia as a cause of death should be diagnosed with caution based on these findings (Figure 1).

A study on the diagnosis of causes of death in adults reported a 32% discrepancy of cases between the diagnoses with postmortem CT scans, those interpreted by radiologists without a specialty in postmortem imaging, and those made by autopsies [3]. With imaging, 32% of bronchopneumonia cases were overlooked in the same study. The majority of lung findings with postmortem CT scans are non-specific and not helpful for establishing the cause of death [4]. Elapsed time since death must be considered as a necessary parameter.

Research methodology and supplementary materials

A search for the words (postmortem, pneumonia, and death) was conducted on PubMed.

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Figure

An autopsy case of pneumonia.
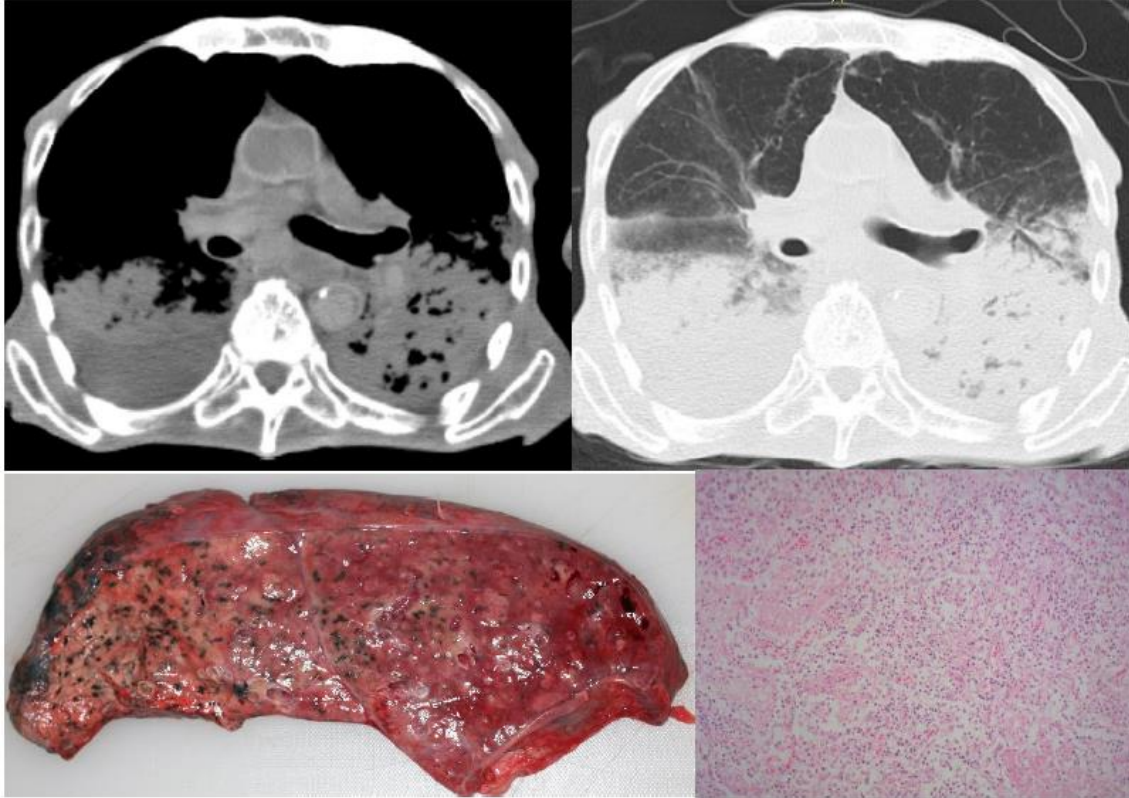
Postmortem CT images show remarkable consolidations and the air bronchogram mainly on the dorsal side of the bilateral lungs (A) and pleural effusion in the right pleural cavity (B). In the autopsy, the left lung was found to be sclerotic and heavy (916g). Macroscopically, the left inferior lobe was solid with a blistered patchy pattern on the surface (C); this was diagnosed as pneumonia. Histologically, with the background of severe emphysema, highly aggregated intra alveolar leukocytes, destroyed alveoli, and fibrin depositions were observed (D).

CQ21 Is postmortem imaging useful when determining death from asphyxia?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

In determining death from asphyxia, there are some uses for postmortem imaging to investigate deaths by obstruction of airways or neck compression from the outside. Foreign objects or masses in the airways, hemorrhages in cervical soft tissue, or fractures of the hyoid bone or thyroid cartilage may show up and these findings can be useful in determining deaths from asphyxia. Improvement of the diagnostic accuracy is expected by using multi-planar reconstructed images if necessary. It is thought that to clearly show findings on postmortem images which are related to the causes of asphyxia will play a supportive role, but the findings may sometimes be modified by resuscitation.

Explanation

Definitions for asphyxia

Unless otherwise noted, asphyxia in the field of forensic medicine is defined as a state mechanical disorder of the external respiration (the processes of the intake of oxygen from the airway inlet to the alveoli and exchange of gases between the alveoli and the blood). Mechanical asphyxia is classified as follows (mainly 1-5):

1. obstruction of nostrils
2. obstruction of the upper airway lumen
3. neck compression from the outside (hanging, strangulation)
4. obstruction of the peripheral airways (drowning and others) (CQ15)
5. breathing disorders (chest or abdominal compression, pneumothorax, and others)
6. abnormalities of the inhaled air or oxygen deficiency (sewerage accidents and others)

Postmortem images of obstruction of the upper airways

It is reported that foreign objects or masses in the nasal cavity or trachea which lead to asphyxia can be identified on postmortem CT/MRI scans [1-8]. Foreign objects in the pharynx or larynx by Iino et al. [1], in the larynx by Oesterhelweg et al. [2], and in the trachea by Aquila have been identified on postmortem CT scans [3]. Thali et al. reported that foreign objects in the airways were clearly identified on postmortem CT scans in a putrefied cadaver one year after interment, and the cause of death

was overturned [4].

It is also reported that metastasis of the tracheal lumen [5] and hemoptysis due to tuberculosis [6] are shown as possible causes of asphyxia except for the presence of foreign objects. In other cases, postmortem CT scans showed that Ludwig angina which is a fatal and severe infectious disease in the submandibular region causes soft tissue swelling and upper airway obstruction [7].

The slice thickness of postmortem CT scans aiming to identify foreign objects causing airway obstruction varies from 0.5 to 2mm [1,2,9]. It is thought that at least a 5mm slice thickness is necessary to obtain images for reconstruction, such as saggital, coronal, or 3D images. If possible, a 1-2mm slice thickness is better. Enhanced CT/MRI scans can provide additional information although it is difficult to evaluate something causing asphyxia or distinguish between foreign objects and lesions using the differences in CT values on unenhanced CT scans [2,4].

Postmortem CT/MRI scans make it possible to assess the state of the airway lumen which is not possible by external examination and is of some usefulness when screening for matters such as foreign objects, masses, and similar which would lead to airway obstruction. An objective assessment for objects which may migrate during an autopsy can also be possible. However, care must be shown in estimating causes of death immediately after the occurrence when asphyxia is suspected to be a result of airway obstruction due to foreign objects and similar. For example, there is a report of a mother who killed her baby by sticking her fingers into the mouth of the baby and then left a number of leaves in the oral cavity [9]. It should be taken into account that there are some situations such as residue refluxes from the stomach and esophagus in the agonal stage, movement of an object in the airway with posture changes of the cadaver, or intentional removal of objects after the death. There are some cases of suspicion of involvement in a crime or need to perform a toxicological examination and it is essential for the diagnosis of death from asphyxia to make a general evaluation with information other than that from postmortem images or other evidence.

Postmortem images of neck compression from the outside

In case of mechanical neck compression (classified into: hanging, ligature strangulation, and manual strangulation), a major cause of death is blocking of the blood flow and oxygen supply to the brain due to the obstruction of cervical vessels. Interpretation of images of asphyxia due to mechanical neck compression is mainly an evaluation of the soft tissue, bone, and cartilage.

Based on postmortem images of hanging, Sohail et al. reported fractures of the thyroid cartilage and laryngeal edema on CT scans [10], and Dubang et al. reported adduction and closure of the vocal cords on MRI images [11]. Aghayev et al. reported that the hyoid bone and thyroid cartilage on CT scans and hemorrhage of the posterior cricoarytenoid muscle on MRI images were identified in the case of ligatures and manual strangulation [12]. In addition, Kempter et al. reported that fractures of the hyoid bone, cricoid, and thyroid cartilage were identified on CT scans in 75% of cases of death from hanging and ligature strangulation. Airway obstruction is not a necessary finding for death from neck compression and fractures of atlas or axis vertebra are not always established.

The MRI findings from cases of survivors from neck compression may be useful. Christe et al. reported cervical subcutaneous and muscle hemorrhage in the case of manual strangulation [14] and Yen et al. reported hemorrhages of the subcutaneous tissue, muscle, lymph node, and salivary glands, laryngeal edema, hematomas of the pharynx and larynx in the case of ligature strangulation [15].

The CT and MRI scans for evaluation of the neck region are useful but not essential. Here, CT scans are superior to evaluate the bone and cartilage and multiple images with multi-planar reconstruction makes diagnostic accuracy higher. However, finding tiny fractures on MRI images is not always easy. For evaluations of the soft tissue structure, MRI images are recommended because the tissue contrast of MRI is better [15] and CT scans may not be appropriate [13]. Findings such as slight hemorrhages which are identified by MRI can be helpful for a diagnosis and combining it with fat-suppression images will be necessary in the choice of scan sequences [12,15].

When the postmortem image findings which suggest asphyxia due to neck compression are poor, it is important to recognize that asphyxia may still be the cause of death. A multiplex diagnosis considering the situation of the death, with external and autopsy findings should be required.

Postmortem images of breathing disorders

Ito et al. reported a case of death from asphyxia by breathing disorder which was a result of chest and abdominal compression by the victim being caught by a truck [16]. The postmortem CT showed a slight hemorrhage around the duodenum and a flattened aorta and inferior vena cava. The cause of death was decided from the petechiae of the eyelids as an external finding and information from the scene.

Other notes

On postmortem imaging, it is difficult to assess petechiae of the face and eyes or postmortem lividity and other signs which are forensic external findings of asphyxia. When a cervical furrow caused by hanging is deep, it has been shown that this finding can be depicted in multi-planar reconstructed images using volume rendering (VR) and similar [17]. To date, there has not been studies about postmortem imaging of internal findings such as congestion of various organs (lungs, liver, kidney, brain, and others). It is unclear if postmortem imaging for nasal obstructions, which is one of the signs of mechanical asphyxia, is useful. Further, chemical asphyxia by carbon monoxide poisoning (classified into poisoning as the cause of death) and mechanical asphyxia from oxygen deficiency cannot be determined by postmortem imaging.

Remarks

Death from asphyxia is occasionally associated with a crime, and further investigation or autopsy should be recommended to the investigating authority while referring the situation of death, external findings, and other matters.

Research methodology and supplementary materials
The following terms were searched for on PubMed: postmortem, forensic, CT, computed tomography, MRI, magnetic resonance imaging, asphyxia, asphyxiation, suffocation, choking, smothering, and airway obstruction. The books entitled "autopsy imaging guide for interpretation" and "autopsy imaging cases series" are also referred to.

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Figure

Figure A case of asphyxia caused by airway obstruction due to "mochi" (a kind of Japanese soft rice cake)

A case of solitary death showed a hyperdense lump of material in the pharynx and larynx. The horizontal plane is observed in the cardiac cavity on the chest CT scan (B) and this suggests flowing of blood and acute death. Although rigor mortis of the jaw was severe and examination of the oral cavity was impossible at the postmortem examination, laryngeal obstruction by "mochi" was identified using rhino-pharyngo-laryngoscopy.

Figure A case of death from hanging
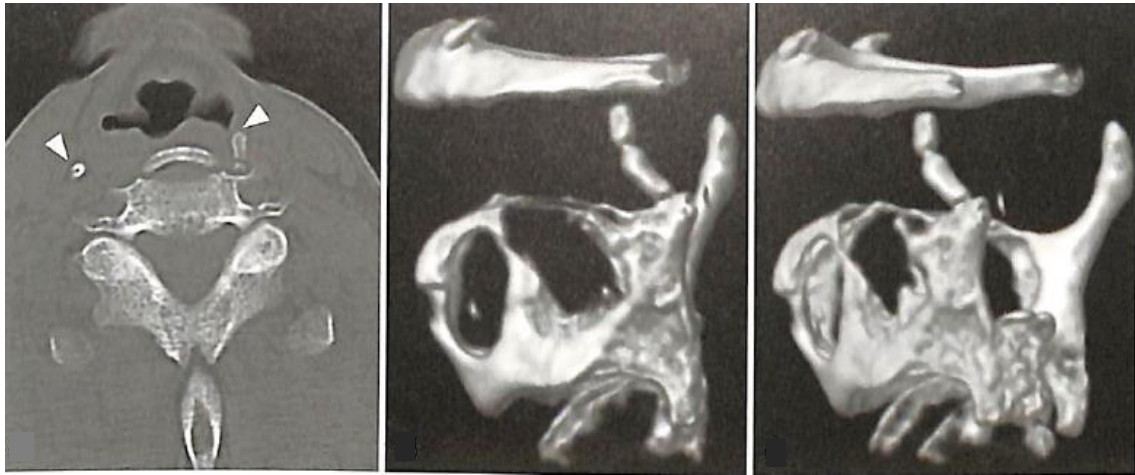
Lateral difference in the position of the superior horn of the thyroid cartilage is observed on the axial image (A). An anterior shift of the left superior horn of the thyroid cartilage is clearly visible on the VR images (B, C).

CQ 22 Is it possible to use postmortem imaging to detect drugs in the stomach?

Grade of Recommendation: C1

> There are reports of hyperdense stomach and duodenal contents being detected on postmortem computed tomography (CT) scans. Postmortem CT scans are useful in detecting radiopaque medications, and toxicological analysis of blood and stomach contents is recommended when there is hyperdense material in the stomach.

Explanation
Background
There are reports of hyperdense stomach and duodenal contents observed on postmortem CT scans confirmed as being oral medications in subsequent autopsies [1-3]. It has also been reported that hyperdense stomach contents were significantly more frequent in a drug overdose group, suggesting a correlation with drug intoxication [1].

Medications
Medications known to be radiopaque include bromine-containing medications such as bromovaleryl urea [2,3]; chloral hydrate, heavy metal and iron salts, phenothiazine, and slow-release preparations [3]. The necessary CT scan numbers of stomach contents in drug intoxication depends on the density of the medication itself, but is also affected by the amount of medication, the amount of food residue, time elapsed after ingestion, and time elapsed after death [2]. Drugs in the stomach and duodenum are often depicted as hyperdense precipitates on postmortem CT scans. A case of organic mercury poisoning was reported as showing hyperdensity along the oral, esophageal, and gastric walls [4].

Significance detecting medications in the stomach
When drugs are retained in the stomach or duodenum, they are sometimes hyperdense on postmortem CT scans. However, an absence of hyperdense masses in the stomach and duodenum does not rule out drug intoxication [2]. In addition, food residue in the stomach is often hyperdense, and it is often difficult to distinguish it from drugs in the stomach. The decision to perform a drug analysis should be made based on all available information, including the circumstances of death.

Some radiopaque drugs cannot be detected in the Triage toxicology screening examination, and when hyperdense stomach contents are detected on postmortem CT scans, drug analysis of blood and gastric contents with the possibility of drug intoxication in mind is recommended [1,3]. However, quantification of drugs on CT scans is difficult [3].

There has been a report of a case in which the circumstances of the death and the hyperdense stomach contents on the postmortem CT scans strongly suggested drug intoxication. The subsequent blood test was positive for mercuric chloride poisoning. Postmortem CT scans helped the forensic medicine staff avoid the risk of mercury exposure during the autopsy and toxicological analysis [4].

Reference

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3. Sano R, et al: A case of fatal drug intoxication showing a high-density duodenal content by postmortem computed tomography. Leg Med 13:39-40, 2011 (level V)

4. Iino M, et al: Post-mortem CT findings following intentional ingestion of mercuric chloride. Leg Med(Tokyo) 11:136-8, 2009 (level V)

Figure

Drug poisoning
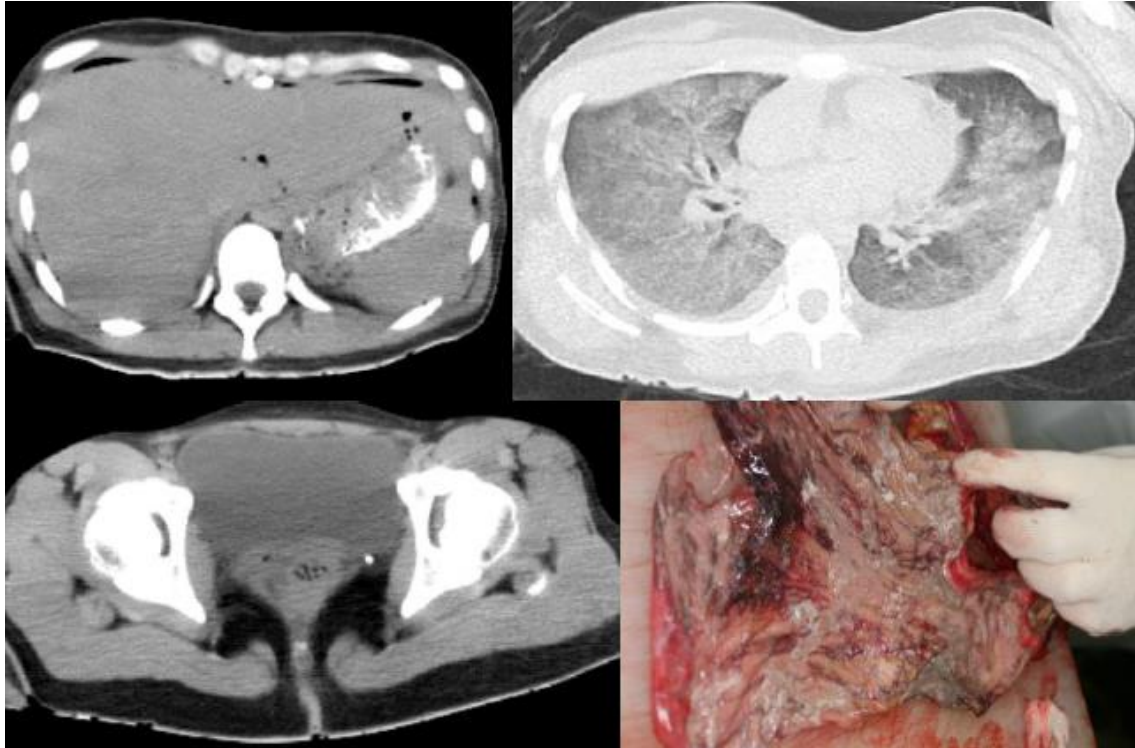
High density material is present in the stomach (a). Bilateral diffuse ground glass opacity is present in both lungs (b), and the urinary bladder contains an extraordinarily large volume of urine (c). These are typical findings in drug poisoning. In the autopsy investigation, a white material was found in the stomach, and a lethal dose concentration of drug was determined in the blood sample.

Figure

Stimulant poisoning and drowning
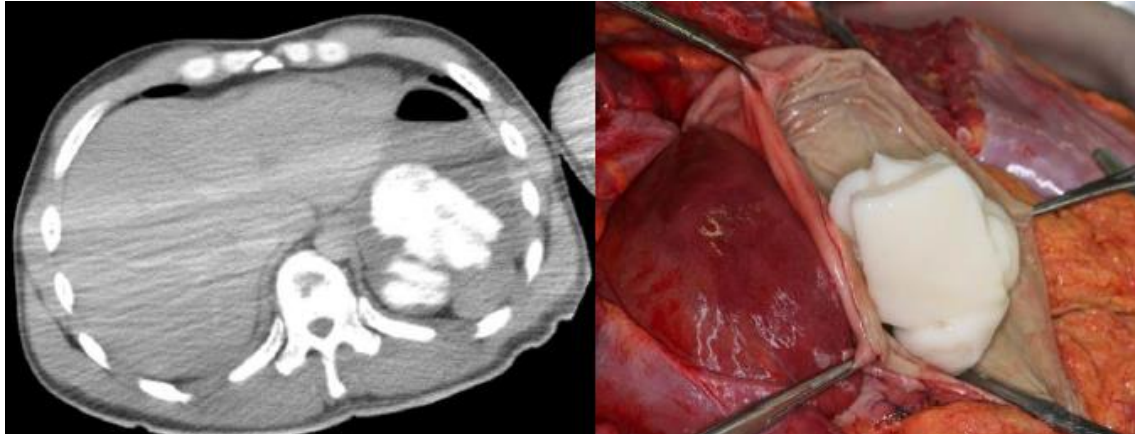
The cadaver was discovered at the bath tub. The injection needle mark was found at the elbow and the drug screening test showed a stimulant positive reaction. On the postmortem CT scan, high density material was present in the stomach, and the cadaver is suspected to be a body packer. At the autopsy, un-chewed putty-consistency rice (MOCHI) was found. Other food like noodles show high densities on CT scans.

CQ23 Is postmortem imaging useful to detect and measure fluid in body cavities?

Grade of Recommendation: C1

Fluid in body cavities can be detected and measured on postmortem CT scans. In comparison with autopsies, the location and relationship to other organs of the fluid is accurately presented on postmortem CT scans. It is difficult to determine fluid collection in some decomposed corpses however. It is also difficult to determine fluid properties, whether serous, suppurative, or bloody, correctly.

Explanation
Background
Fluid collected in the sinonasal cavities, trachea, pleural cavities, pericardial cavities, peritoneal cavities, and retroperitoneal cavities has been detected on postmortem CT scans, and were confirmed by autopsies in many reports. It was reported that small amounts of fluid collected in the pleural or pericardial cavities, which were not noted by autopsies, were present on postmortem CT scans. Le Blank-Louvry et al. reported that the detection rate of abdominal fluid collections on postmortem CT scans is higher than that by autopsies. However, Poulsen et al. reported that it is difficult to detect small volumes of abdominal fluid on postmortem CT scans in decomposed corpses because of intestinal and peritoneal gases.

Quantitative analysis of fluid collected in body cavities
Some studies reported that the amount of peritoneal blood or peritoneal fluid was accurately measured on postmortem CT scans.

A comparison with autopsies
Because fluid moves during autopsies, it is difficult to determine its exact location in body cavities. It is however possible to demonstrate the location and relationship to other organs of fluid accurately on postmortem CT scans. Christoffersen reported a case with compression to the mediastinum by a large volume of pleural effusion, where the relationship between fluid and mediastinum was not detected by the autopsy.

Blood collection in body cavities

Blood is usually shown as high opacities on postmortem CT scans. However the opacity of blood in body cavities changes according to the conditions at the death or after the death. As a result, it may be difficult to distinguish among fluid characteristics, serous, suppurative, or blood. When characteristics of fluid in body cavities are evaluated, it is important to record the conditions involved at death or after death.

Reference

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9. Cha JG, et al: Utility of Postmortem Autopsy via Whole-Body Imaging: Initial Observations Comparing MDCT and 3.0T MRI Findings with Autopsy Findings. Korean J Radiol 11(4):395-406, 2010 (levelIV)

10. Christe A, et al: Abdominal trauma--sensitivity and specificity of postmortem noncontrast imaging findings compared with autopsy findings. J Trauma 66(5):1302-07, 2009 (levelIV)

11. Miyamori D, et al: Temporal evolution in peritoneal hemorrhage as depicted by postmortem CT. J Forensic Leg Med 20(5):548-50, 2013 (levelV)

12. Ampanozi G, et al: Post-mortem virtual estimation of free abdominal blood volume. Eur J Radiol 81(9):2133-6, 2012 （levelIV）

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15. Poulsen K, et al: Computed tomography as routine in connection with medico-legal autopsies. Forensic Sci Int 171(2-3):190-7, 2007 （levelV）

Figure

Drowning
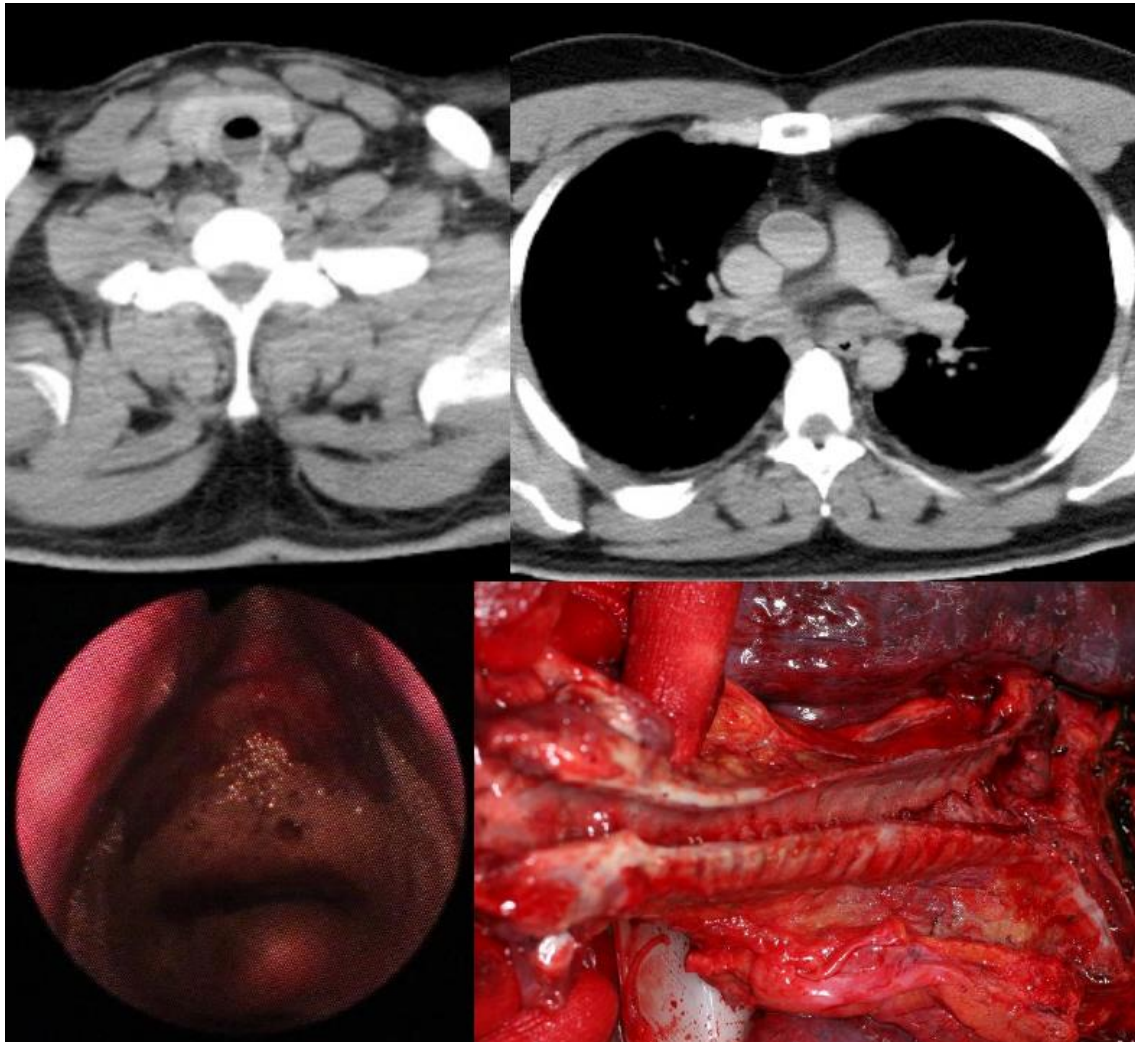
On the postmortem CT scan, the air-fluid level is present from the larynx to the trachea (a), and bronchus (b). Bilateral pleural space fluid is also present on the chest CT scan. Using a tracheal fiberscope, white small bubbles were identified just beside the vocal cord with fluid (c). At the autopsy, there were tracheal bubbles, but the fluid leaked out during the procedure.

CQ 24 Is it possible to use postmortem imaging to detect and quantify gas in corpses?

Grade of Recommendation: C1

There are reports of detecting abnormal gas volumes in different parts of the body on postmortem computed tomography (CT) scans. Detection of internal gas on CT scans is easier than at autopsies, and image reconstruction enables quantification. Intravascular gas often develops during normal postmortem changes and resuscitation, but it may also be due to air embolism. The cause of intravascular gas must be carefully identified by quantity and distribution, and the time elapsed after death must also be noted. Gas in the abdominal cavity is an indirect finding suggesting gastrointestinal perforation, but it is necessary to distinguish this gas from that due to gastric perforation caused by postmortem autolysis. It is difficult to estimate the elapsed time after death by detection of internal gas alone.

Explanation
Background
There are reports of detecting abnormal gas in various parts of the body on postmortem CT scans. Gas within organs such as the liver, kidneys, spleen, and pancreas [1,2]; intravascular gas such as in the aorta, heart, and coronary artery [2-6]; and intracranial emphysema, mediastinal emphysema, pneumothorax, pneumoperitoneum, and retroperitoneal emphysema [4,5,7] have been reported to be clearly depicted on postmortem CT scans.

Non-traumatic death
Intravascular gas in cases of non-traumatic deaths has two potential origins: decomposition and cardiopulmonary resuscitation (CPR) [1].

Decomposition begins immediately after death, and the generated gas is evenly distributed in the abdominal organs. It is difficult to estimate time elapsed after death from the distribution of gas on postmortem CT scans [1]. But when intravascular gas is determined in cases with images obtained more than one day after death, decomposition should be considered a potential source of the gas, since findings of putrefaction appear on CT scans around 1-2 days after death [2]. There is a report of a case in which intravascular gas on a CT scan made several hours

posthumously was diagnosed as a finding of decomposition [3], but details of the gas were not analyzed.

There is also a report associating CPR with gas retention in the liver and kidneys [1] and such a finding can be helpful to distinguish the origin of the internal gas. In addition, intracardiac and intravascular gas caused by CPR is thought to flow into the brain vessels in a retrograde manner [3].

Intravascular gas, subcutaneous emphysema, mediastinal emphysema, pneumothorax, pneumoperitoneum, and retroperitoneal hemorrhages caused by intentional gas infusion into the blood vessels have been reported to be clearly depicted on postmortem CT scans [5,6]. Image reconstruction is useful for recognizing the distribution of the gas in the body and for quantifying the gas [6,7]. However, it has been reported that intra-arterial or intravenous infusion of gas from the limbs can cause fatal air embolisms even in small quantities depending on the infusion rate [8], and it may be difficult to decide the cause of death from postmortem CT scans alone.

Free gas in the abdominal cavity on postmortem CT scans must be interpreted carefully, because this gas can be due to gastric perforation caused by autolytic rupture of the stomach after death [9,10]. In the absence of findings indicating decomposition and peritonitis on postmortem CT scans, abdominal free air may be the result of gastric perforation due to postmortem autolysis.

Traumatic death

There are many reports of cases with arterial air embolisms after chest injuries, and traumatic pulmonary alveolo-venous fistulas are considered to be the main cause [4]. It has also been reported that head and neck injuries cause venous air embolism [7]. Arterial embolisms from venous gas, the so-called paradoxical embolism, may be seen in patients with right-to-left shunt such as foramen ovale and pulmonary arteriovenous fistula [5,6]. These arterial air embolisms are sometimes the cause of death, and the detection of intravascular gas is helpful in finding the probable cause of death. However, estimating the time elapsed after death is difficult [1].

Reference

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Figure

Pan peritonitis due to traumatic intestinal rupture
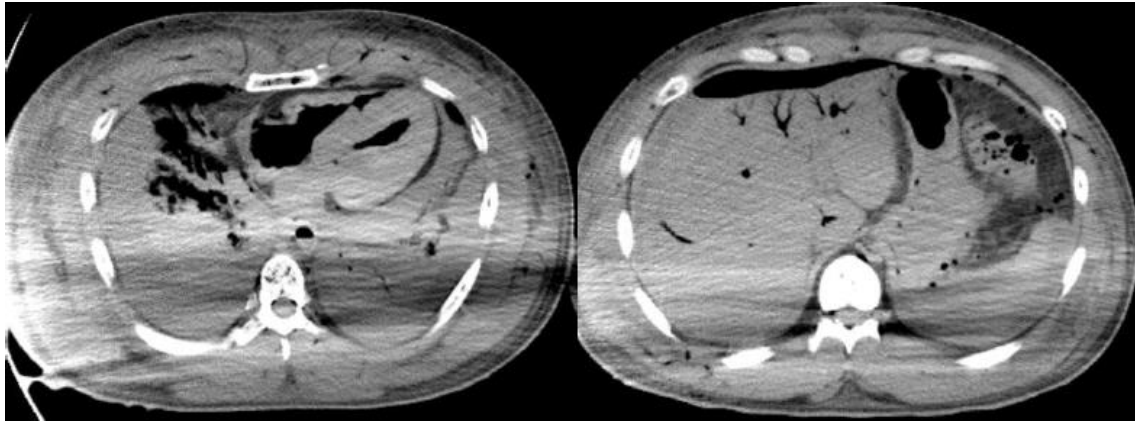
Intra-cardiac and intra-vascular gas is present, but there is no subcutaneous gas formation (a). There is peritoneal free air and peritoneal fluid collected at the liver and splenic surface (b). Gastro-intestinal perforation is expected from these CT image findings. At the autopsy, pan peritonitis due to traumatic intestinal rupture was confirmed.

CQ25 Is postmortem imaging useful in determining rib fractures arising from cardiopulmonary resuscitation?

Grade of Recommendation: C1

Postmortem imaging is useful in determining rib fractures due to cardiopulmonary resuscitation (CPR) in case of nontraumatic cardiac arrest. Computed tomography (CT) is superior in this diagnosis because conventional chest X-ray images are insufficient to determine such fractures. Localization and a qualitative diagnosis by reconstructed images from CT scans may enable distinguishing between fractures associated with CPR and fractures due to other causes.

Explanation

Chest compression is necessary during CPR after cardiac arrest. For adults compression with a vertical depth of 5 cm in the supine position, is recommended. Fractures in the ribs and sternum due to chest compression during CPR are frequently reported in adults, although the incidence varies among studies.

A characteristic finding of rib fracture due to CPR is the "buckle fracture," a type of incomplete rib fracture that involves either the outer or the inner cortex alone. Over 95% of rib fractures associated with CPR are located in the anterior ribs, mostly from the second to the seventh rib. If fractures are located in the posterior ribs, the possibility of trauma other than CPR-associated trauma should be considered[1]. In detecting buckle fractures, CT scans have been shown to be superior to autopsies and conventional X-ray images for a diagnosis[2], further, autopsies are superior to conventional X-ray images[3]. In patients where there is no resumption of autonomous circulation after CPR, hemorrhagic complications are rarely due to CPR-associated rib fractures[3].

However, in cases in which chest compression was performed by AutoPulse, an automated chest compression device, posterior rib fractures occur with a high frequency[4]. In a study investigating 13 cadavers subjected to chest compression by the LUCAS CPR, another automated chest compression device, the incidence and locations of rib fractures were similar to those caused by manual CPR, and autopsies identified more fractures than CT scans[5].

Research methodology and supplementary materials

The following terms were searched for on PubMed with parameters defined to be

within the past 10 years: postmortem CT, CPR, rib fracture, and autopsy. Referenced documents in the resulting articles and other useful papers have also been cited, as well as studies of survivors from chest compression.

References

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3. Lederer W et al. Frequency of rib and sternum fractures associated with out-of-hospital cardiopulmonary resuscitation is underestimated by conventional chest X-ray. Resuscitation 60:157-62, 2004 (level 5)

4. Pinto DC et al. Manual and automated cardiopulmonary resuscitation (CPR): A comparison of associated injury patterns. J Forensic Sci 58(4):904-909, 2013 (level 4)

5. Oberladstaetter D et al. Autopsy is more sensitive than computed tomography in detection of LUCAS-CPR related non-dislocated chest fractures. Resuscitation 83: e89-90, 2012 (level 5)

Figure

An autopsy case of pericardial hematomas due to ruptured dissection of an aneurysm of the thoracic aorta
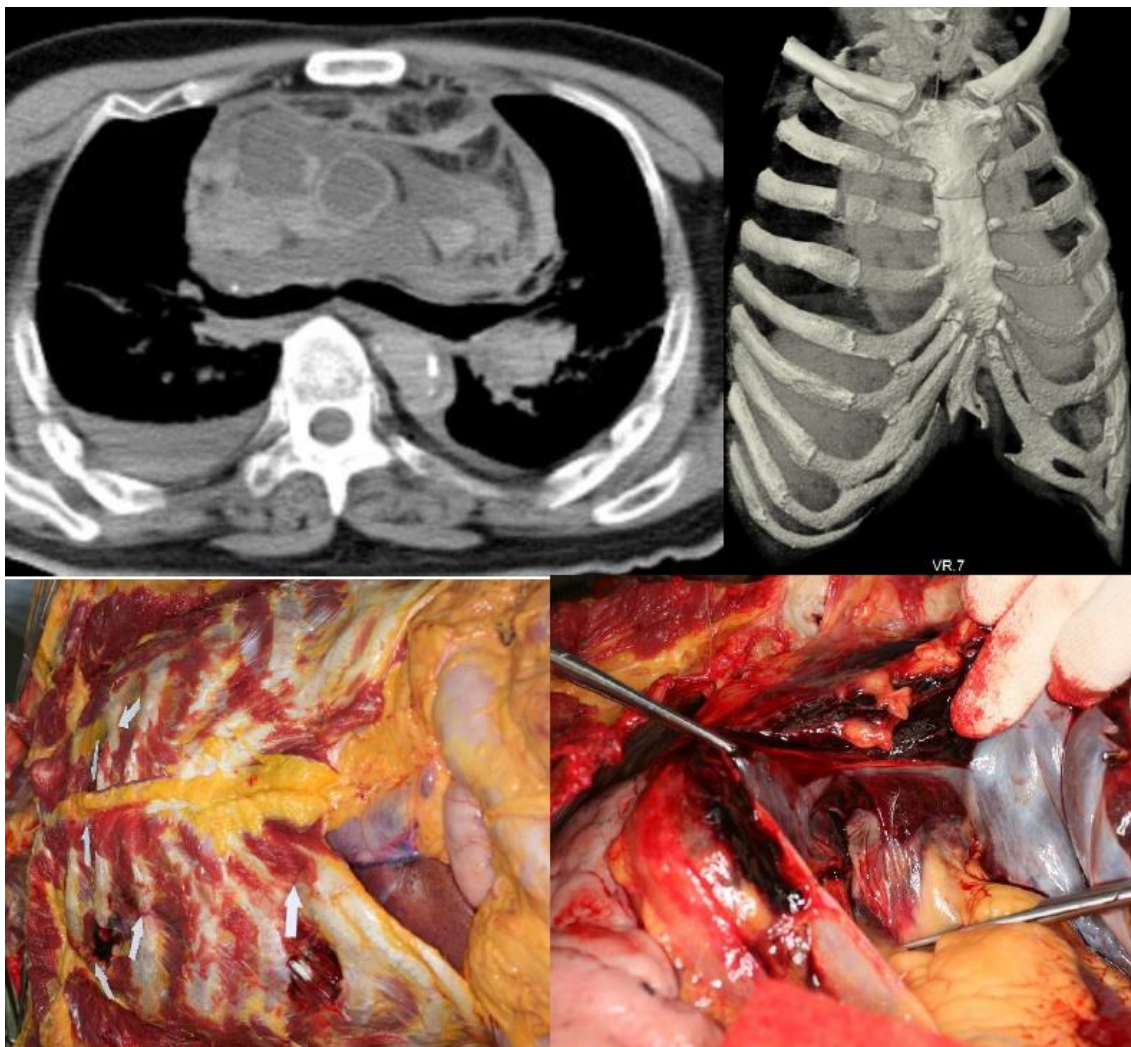
Confirmed dead without response in attempt at CPR. The right third rib was dislocated (A, B), here considered a fracture caused by an external force from the front. The presence of pericardial and mediastinal hematomas and right hemothorax indicated the possibility of traumatic cardiovascular rupture. A fluid-fluid level in the right pleural cavity (A, arrowheads) indicated the possibility of blood with fluidity leaking into the cavity. During the autopsy, only a small amount of hemorrhaged liquid around the fracture was evident (C); however, evaluation of the extent of the hemorrhage by CT scans was difficult. If the fractures had accompanied a major dislocation, they could have been detected with

volume rendering (VR) images; however, some small fractures were difficult to detect. As the autopsy showed contusions and lacerations between the intrapericardial aorta at the level of the pericardial reflection and the right hilar parietal pleura (D, arrows), it was considered that the pericardial hematoma had leaked into the mediastinal connective tissue and the pleural cavity by chest compression.

CQ26 Is postmortem imaging useful in diagnosing visceral injuries due to cardiopulmonary resuscitation?

Grade of Recommendaton: C2

> Postmortem imaging is useful in diagnosing visceral injuries due to cardiopulmonary resuscitation (CPR) in case of nontraumatic cardiac arrest. Previous studies have suggested that intraperitoneal gas introduced by gastric perforation and pneumothorax associated with chest compression could also be detected by postmortem imaging. In detecting liver and splenic injuries, postmortem computed tomography (CT) scans with contrast agents is useful.
>
> As the incidence of intraperitoneal hemorrhages associated with liver and spleen injuries increases after death and may affect the diagnosis of the cause of death, a CT scan immediately after death is recommended.
>
> A small amount of liquid from pericardial or mediastinal hematomas due to chest compression should not be considered as a cause of sudden death.

Explanation

Because interventions such as chest compression and positive pressure ventilation are performed during CPR after cardiac arrest, there are many reports of visceral injuries after the circulation is restored[1][2]. For thoracic organs, cases such as cardiac tamponade due to pericardial and cardiac injuries (Figure) and hemothorax due to lung injuries have been reported. For abdominal organs, cases such as gastric perforation and liver and spleen injuries have also been reported. Cases of mortality have also been attributed to visceral injuries as a complication resulting from surgical procedures, in which hemorrhagic lesions were identified by postmortem CT scans with a contrast agent[3]. Overall, postmortem CT scans with a contrast agent are useful in distinguishing between visceral injuries due to chest compression and primary visceral injuries due to other causes.

In general, visceral injuries as a complication with chest compression are not accompanied by massive hemorrhages. A case of traumatic death was reported, in which the initial postmortem CT scan obtained immediately after death showed no massive peritoneal hemorrhage but the autopsy identified a remarkable increase in hemorrhaged volume after the death; therefore, a CT scan immediately after death is recommended to distinguish between primary antemortem injuries and injuries

associated with chest compression[4].

Research methodology and supplementary materials
The following terms were searched for on PubMed with parameters defined to be within the past 10 years: postmortem CT, CPR, injury, complication, and autopsy. Referenced documents in the resulting articles and other useful papers have also been cited.

References
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liver injury. Resuscitation 75:445-53, 2007 (level 5)
2. Miller AC et al. A systematic review and pooled analysis of
CPR-associated cardiovascular and thoracic injuries. Resuscitation 85:724-31, 2014
(level 5)
3. Zerlauth JB et al. Surgical interventions with fatal outcome:
Utility of multi-phase postmortem CT angiography. Forensic Sci Int 225:32-41, 2013
(level 5)
4. Miyamori D et al. Temporal evolution in peritoneal hemorrhage as
depicted by postmortem CT. J Forensic Leg Med 20:548-50, 2013 (level 5)

Figure

An autopsy case with a noteworthy secondary injury associated with attempted CPR
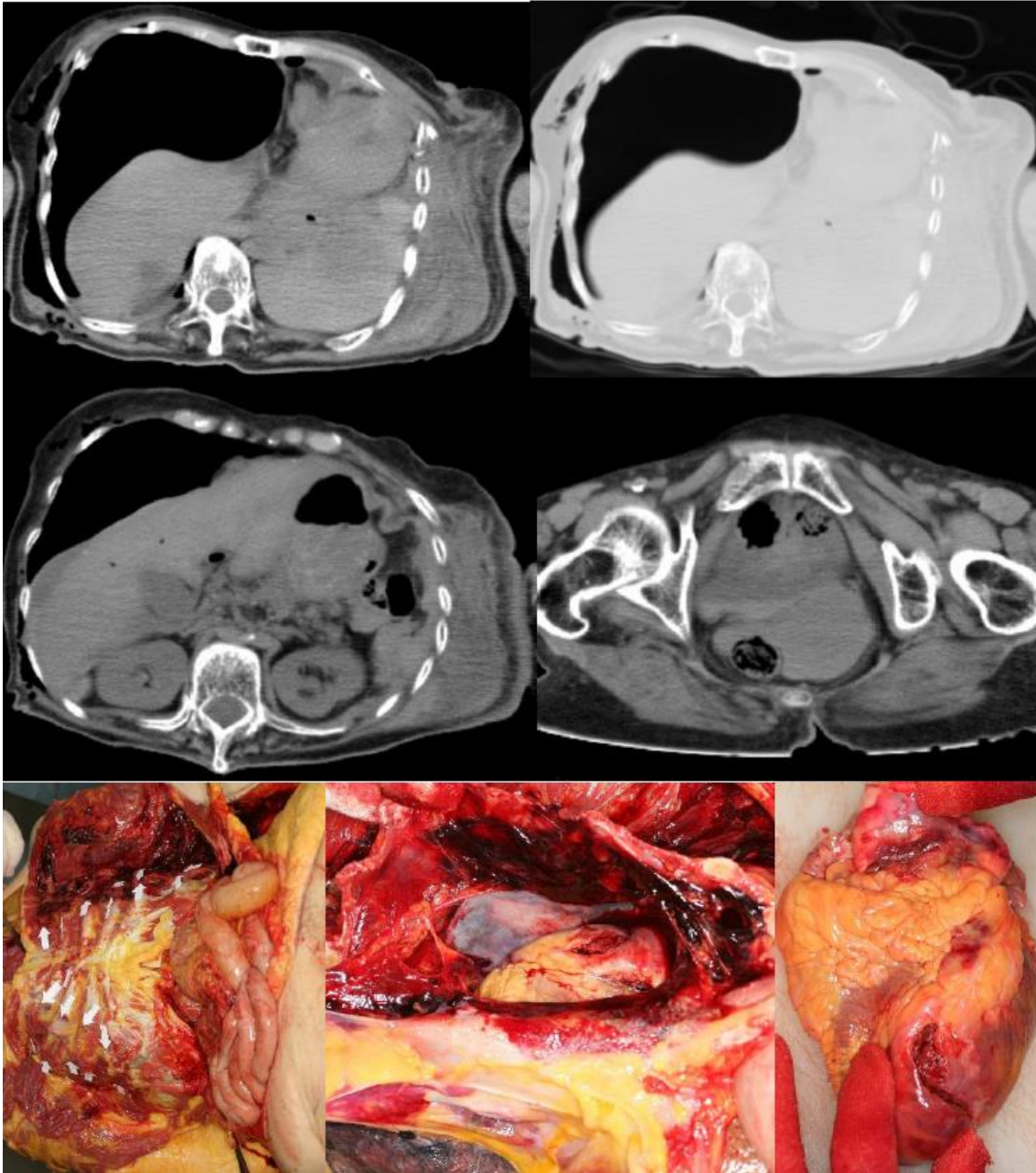
A case of a sudden collapse followed by disturbance of consciousness in front of a dentist who visited the patient's home. Despite an immediate CPR attempt, the patient was confirmed dead on arrival at the hospital. Postmortem CT scans showed multiple rib fractures, right pneumothorax, mediastinal shift to the left, left hemothorax (coagulation), massive hematomas in the muscles of the left chest and

back, and subcutaneous emphysema of the right chest (A, B, C). Effusion in the abdominal cavity was also obvious (D), indicating injuries and hemorrhages in abdominal parenchymal organs. During the autopsy, extensive thoracic fractures were also identified. The right thoracic wall fractures were not accompanied by any hemorrhage, but a massive hemorrhage was obvious in the muscles of the left thoracic wall that communicated with the intrapleural space (E). Contusion in the left lobe of the liver (below the xiphoid process) was evident, and 430 mL of blood with fluidity was accumulated in the peritoneal cavity. The pericardial membrane was wide open, and the heart had moved deviated to the left pleural cavity (F) containing 340 mL of coagulated blood. A large laceration from the anterior wall to the apex of the heart was identified (G, arrowhead), and was pathologically diagnosed as a cardiac rupture after myocardial infarction. This remarkable secondary injury as a complication of a CPR attempt modified the pathophysiological condition at death.

CQ27 Is postmortem imaging useful in diagnosing causes of death during external examinations of cadavers?

Grade of Recommendation: C1

It is useful to apply postmortem imaging to external examinations of corpses since the cause of death may be diagnosed with the images inspected. It may help determining if there are external cause of death for a corpse. It can also assist in determining injuries or foreign matter inside the corpse.

However, caution is needed in the interpretation since there are many pathological conditions which could be missed by postmortem CT scans.

Explanation

The forensic autopsy rate for unnatural deaths in Japan is approximately 10%, extremely low compared to other developed countries [1,2]. If a case is believed to be due to natural death, not involving anything criminal at the time of inspection by a police officer or a physician, the body will be cremated without being autopsied [1]. Postmortem imaging is thought to be a useful tool for detecting injuries or pathological conditions which are overlooked by external examinations [1].

Diagnostic rate by postmortem imaging

A study comparing the findings of postmortem imaging and autopsies reported that the diagnosis of causes of death with CT scanning alone was 80% in traumatic deaths and 30% in non-traumatic deaths [2]. Hemorrhagic diseases such as cerebral hemorrhages, subarachnoid hemorrhages, dissection of the aorta and ruptures of abdominal aortic aneurysms can be diagnosed by postmortem CT scans. The images should be interpreted by radiologists or forensic pathologists familiar with postmortem CT scan interpretation through experience in comparing autopsies and CT findings [1].

Preventing overlooked crimes and accidents

In a study by Iwase et al., of 80 cases where the police determined a death as death by disease with no element of criminality in their initial investigations, external causes were shown by postmortem CT scans in 8 cases (10%) [1]. A CT scan may be used as a tool for preventing such overlooked cases of external causes [1].

Postmortem CT scans were found to be useful as a screening and documentation

method for stomach contents in cases where oral medication intoxication is considered.

In drug overdose cases, postmortem CT scans can be used as a screening tool. In non-suspicious cases with common findings and negative external examinations, a basal radio-opaque layer in the stomach of >100 HU is strongly suggestive of an intentional drug overdose [3]. Postmortem CT scans can also identify overlooked cases of asphyxia by choking since they enable detection of laryngeal foreign elements invisible by external examination [4-6].

Avoid autopsies in the case of infectious diseases

Some studies report that rapid toxicological tests and care in scanning and interpreting postmortem CT scans can reduce the number of autopsies helping to avoid infection from cases of high-risk infectious diseases such as HIV or HCV positive cases.

Combinations with other examinations

Although the rate of diagnosis of causes of death with CT scanning alone is low [1], a combination of plain CT scans, postmortem CT angiography, and biopsies, representing a minimally invasive approach has delivered noteworthy results [7]. Such minimally invasive approaches have led to correct diagnosis of the cause of death in 90% of the studied cases [7]. The clinical notes will also help to ensure that the post-mortem examination provides the most accurate and comprehensive information regarding the cause of death [8].

Pathology findings that may be overlooked or invisible by postmortem CT scans

Postmortem imaging findings were not helpful in reaching a definitive diagnosis of ischemic cardiac disease, chemical addiction, metabolic disorders, and inflammatory entities [1]. Further, CT scans may also miss cervical spine injuries, cardiac ruptures, injuries to hollow organs, diaphragmatic injuries, and hemomediastinum [1]. There are some important autopsy findings which have not been identified with CT-scanning, including non-calcified severe coronary atherosclerosis, coronary thrombosis, pulmonary embolisms, bronchiectasis, emphysema, liver or spleen contusions, severe aspiration/boluses, micronodular cirrhosis, fractures of the cranial base, chronic gastrointestinal ulceration (duodenum and esophagus) and more [9]. There have been unexpected microscopic findings at autopsies, including microscopic occulted cancers, chronic lymphatic

leukaemia, disseminated sarcoidosis, bronchopneumonias, and pulmonary tuberculosis [9].

Important CT findings that tend to be missed by autopsies

Important CT findings overlooked at autopsies are fractures (extremities, pelvis, facial skeleton), pneumothorax, bone metastases, hydrothorax with cardiac compression, subcutaneous emphysema [9].

Postmortem CT findings of fetuses

At present, the only evidence based use of postmortem MRI scanning as an adjuvant to autopsies is in cases of fetal brain abnormalities [10].

PubMed 2014/2/25

#1   Search (postmortem CT) OR (postmortem computed tomography)

#2   Search (causes of death) AND (autopsy)

#3   Search (#1) AND (#2)

#4   Search (#3) AND English[Language] Filters: published in the last 10 years

Results 196

#5   (#4) AND (external examination)検索結果 5

#6   (#4) AND (choking)検索結果 7

Japanese Medical Library 医中誌

（死後 CT）OR（死後画像）検索結果 292

Reference

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4. Oesterhelweg L, et al: Virtopsy: postmortem imaging of laryngeal foreign bodies. Arch Pathol Lab Med 133(5):806–10, 2009 （levelⅤ）

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CQ28 Is it useful to use postmortem radiography before autopsies?

Grades of recommendations: C1 for evaluating the condition

C2 for determining the cause of death

Postmortem CT is useful to record the findings which may disappear by autopsies, such as the quantity and location of the gas. In addition, the autopsy has difficulty to investigate whole body bones, but postmortem CT may record it objectively.

According to the operators' medical safety, postmortem CT is also useful to arrange facilities / equipment before autopsy in case of high risk infections.

There are cases where findings about bones are useful for identification, such as the bone configurations, or scars from orthopedic surgery. That kind of information makes a detailed autopsy necessary.

While discussing whether radiological diagnosis will be an alternative method to conduct the autopsy, there is a further reputation to combine postmortem imaging with autopsy.

Explanation

There are few documents, which examined whether pre-autopsy post-mortem imaging is useful or not, and some reports, where it is only described as experience or comment.

In any case, whole body search with CT scans is useful for detection of gas, bone components, metals, and for other reasons.

1. Whole body CT is useful as pre-autopsy imaging shows findings of irregularly deformed bullets and their fragments, bone fragments, and infected areas like for tuberculosis. We can prepare the clothes and equipment necessary for autopsy with assurance of safety and quality, and also pay attention during autopsy. (1)

2. We can obtain the valuable information about forensic anthropology. (2)

3. Postmortem imaging was very useful for investigating many unidentified copses at forest fires. In burned bodies, it is impossible to examine the external surface, fingerprints, teeth, and DNA. However, we can get much information from

postmortem imaging, such as skeleton, arteriosclerosis, metal medical material, etc. In 61% of cases gender could be determined on CT scans. Age range could be determined on CT in 94% of cases with an accuracy of 76%. (3)

Reference
1. Rutty GN, et al: Accuracy of magnetic resonance imaging in determining cause of sudden death in adults: comparison with conventional autopsy. Histopathology 44(2) 187-9, 2004 （levelⅣ）
2. Dedouit F, et al: Virtual autopsy and forensic identification-practical application: a report of one case. J Forensic Sci 52(4):960-4, 2007 （levelⅤ）
3. O'Donnell CJ, et al: Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: Experience gained from the 2009 Victorian bushfires. Forensic Sci Int 25;205(1-3):15-28, 2011 （levelⅣ）

Figure

burning to death
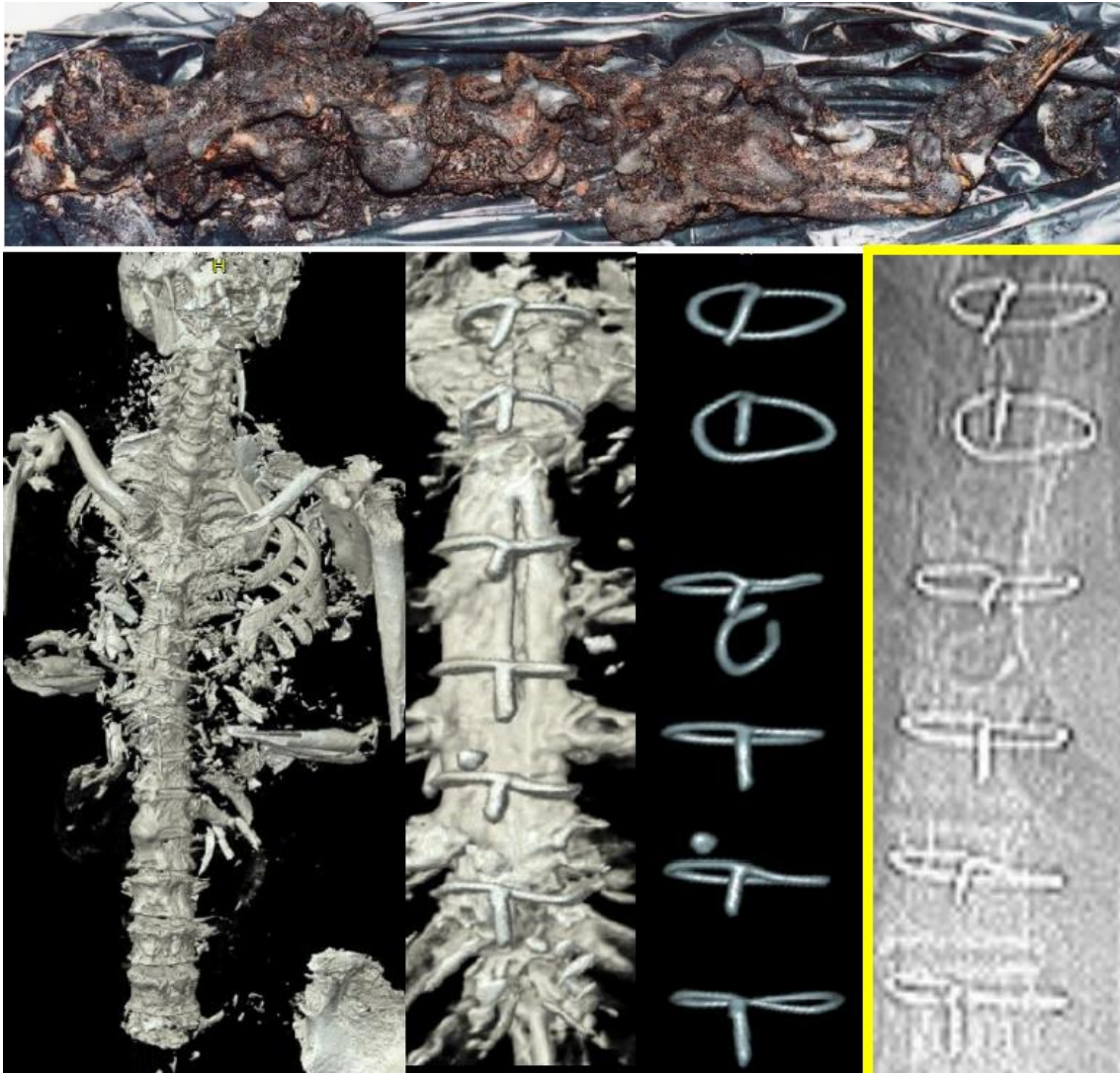
At the macroscopic investigation, almost all of the arms and feet are lost by burning. The three cavities: head, chest, and abdomen, are opened, and the organ investigation is difficult (a). Using CT 3 dimensional imaging, there are sternal bone wires (b,c). For the identification, a person with a history of mitral valve replacement would be a candidate. The postmortem CT image (d) and clinical chest XP image (e), those are used to compare the metallic placement, and the wire shapes match.