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PAPER

PATHOLOGY/BIOLOGY

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Blood Aspiration as a Vital Sign Detected by Postmortem Computed Tomography Imaging

ABSTRACT: Blood aspiration is a significant forensic finding. In this study, we examined the value of postmortem computed tomography (CT) imaging in evaluating findings of blood aspiration. We selected 37 cases with autopsy evidence of blood in the lungs and/or in the airways previously submitted to total-body CT scanning. The CT-images were retrospectively analyzed. In one case with pulmonary blood aspiration, biopsy specimens were obtained under CT guide for histological examination. In six cases, CT detected pulmonary abnormalities suggestive of blood aspiration, not mentioned in the autopsy reports. CT reconstructions provided additional data about the distribution and extent of aspiration. In one needle-biopsied case, the pulmonary specimens showed blood in the alveoli. We suggest the use of CT imaging as a tool complementary to traditional techniques in cases of blood aspiration to avoid misdiagnosis, to guide the investigation of lung tissue, and to allow for more evidence-based inferences on the cause of death.

KEYWORDS: forensic science, forensic imaging, forensic pathology, blood aspiration, computed tomography, needle biopsy

One of the most important issues in forensic pathology is assessing whether an injury occurred before or after death. Traditionally, the evidence for pre- or postmortem injury is based on autopsy, histopathological, and biochemical findings (1–7). These are mainly dependent on the presence of intact circulation, respiration, metabolic phenomena, or consciousness after the damaging event.

Because breathing exclusively depends on the activity of the central nervous system, it is possible to attribute a high degree of reliability to signs of vitality based on intact respiration, given that it ceased together with cardiovascular arrest or brain death. Thus, the diagnosis of aspiration carries great forensic relevance. Although an iatrogenic origin because of pulmonary resuscitation maneuvers and the postmortem flow of foreign material into the trachea and bronchi should first be ruled out (1,5), the presence of blood deep in the respiratory tract is traditionally considered a vital phenomenon (1–7). Moreover, depending on the volume of blood aspirated, it may be interpreted as the primary or, more frequently, contributing cause of death.

A large number of deaths examined by forensic pathologists are related to situations that could lead to blood aspiration. Examples include deaths due to a gunshot, stabbing and blunt injuries, or vehicular accidents, including air crashes (8,9). Rarely, deaths due to lung tumors, bronchiectasis, tuberculosis, etc. (10) may result in blood aspiration.

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Blood can reach the intrapulmonary airways not only in an anterograde manner (8,9), as in traumatic injuries involving fractures of the skull base opening into the naso- and oropharynx, but also in a retrograde manner, proceeding from an injury located beneath the bronchial tree in the pulmonary parenchyma (10–12). It has been shown, in fact, that expiratory and inspiratory movements involve not only the central regions of the lungs but also the periphery. Thus, in cases of pulmonary contusion, laceration or destruction of the lung tissue structure, blood escapes from the damaged parenchyma into the alveoli and bronchioles. Generally, blood aspirated in a retrograde manner due to peripheral injuries is minimal, far less than that seen in cases of anterograde aspiration, and is localized in close proximity to the damage (12).

Traditionally, the diagnosis of blood aspiration is based on the macroscopic presence of red, rounded areas with a patchy distribution either on the lung surface or on cut surfaces, eventually confirmed by the finding of blood filling the alveoli and bronchioles upon microscopic examination (1).

The increasing use of new cross-sectional techniques in forensic medicine (13–31) prompted us to evaluate the diagnostic role of postmortem CT imaging in cases with autopsy and/or histological evidence of blood aspiration in the parenchyma or with autopsy detection of blood or bloody fluids in the airways.

Materials and Methods

Study Population

The responsible justice department and the Ethics Committee of the University of Bern approved this study. Between January 2005 and December 2008 at the Institute of Forensic Medicine in Bern, a total of 359 human corpses underwent multislice computed tomography (MSCT) scanning prior to autopsy as part of the Virtopsy® project. We selected 37 cases for retrospective analysis. The selection criteria were the following: (i) documentation of blood aspiration of any type (anterograde and/or retrograde) and any severity upon macroscopic and/or microscopic examination or (ii) evidence of blood or bloody fluids in the airways from the larynx to the first branches of the bronchi seen upon autopsy inspection. Cases were excluded if resuscitation maneuvers with artificial respiration were performed. In the final study population, there were 27 (73%) male subjects and 10 (27%) female subjects with an age range of 3–82 years and a mean age at death of 42.5 years (Table 1). MSCT and autopsy were performed on all bodies at a median of 43 and 58 h after death, respectively.

Autopsy Techniques and Interpretation

The autopsies were performed by three board-certified forensic pathologists who carried out complete dissection and gross inspection of the body cavities and organs. Organ weights and body cavity fluid volumes were recorded. The respiratory system was removed in one block, and the airways and pulmonary blood vessels were dissected and inspected. The lungs were examined by cutting sequentially from the apex to the base in 1- to 2-cm parasagittal slices.

Tissue samples from all of the organs, including both lungs, were obtained for histological examination. All of the pulmonary specimens were stained with hematoxylin and eosin, and the three forensic pathologists analyzed each slide under the microscope.

A toxicological examination was performed in each case, and each autopsy report included digital photographs of the external examination of the body and the macroscopic inspection of the organs and cavities.

The cause and manner of death for each subject were determined after a complete autopsy was considered in light of toxicological findings, circumstances of death, and clinical data.

The autopsy reports were reviewed for descriptions of blood or bloody fluids in the larynx, trachea, main bronchi and small bronchi, along with evidence of red, rounded areas with a patchy distribution on the pulmonary surface or on cut surfaces. The mode of aspiration and the contribution of blood aspiration to the death of each subject were also considered.

TABLE 1—*Sex and age for each case.*

Case Number	Sex	Age (years)
01.	M	24
02.	F	64
03.	M	22
04.	M	41
05.	M	46
06.	M	27
07.	F	41
08.	M	45
09.	M	19
10.	M	16
11.	M	54
12.	F	22
13.	M	58
14.	F	51
15.	M	39
16.	F	42
17.	M	26
18.	M	76
19.	M	38
20.	F	38
21.	M	62
22.	F	77
23.	M	52
24.	M	25
25.	M	54
26.	M	46
27.	M	35
28.	F	82
29.	M	76
30.	F	20
31.	M	43
32.	M	34
33.	M	75
34.	F	45
35.	M	31
36.	M	50
37.	M	3

Imaging and CT-Guided Biopsy Techniques and Interpretation

According to the Virtopsy® protocol, the corpses underwent whole-body CT scanning on a Somatom Emotion 6 scanner (Siemens Medical Solutions, Forchheim, Germany). Subjects were scanned naked, and three series of images were obtained: series 1 was obtained from the skull vertex to the laryngeal plane; series 2, from the laryngeal plane to the proximal femur, with arms raised to the sides of the head; and series 3, from the proximal femur to the toes. In series 1 and series 3, the cadavers were scanned with a collimation of 4×1.25 mm. In series 2, including the thorax, they were scanned with a collimation of 6×1 mm. No contrast medium was administered, and the reconstruction interval was 0.7 mm in all series. The examination took 10–15 min. Two- and three-dimensional reformations and reconstructions were obtained using a Leonardo workstation (syngo CT software; Siemens Medical Solutions). A board-certified radiologist retrospectively analyzed the images.

The date, mechanism, and cause of death, along with the body position after death and external examination findings, were known by the radiologist; however, he did not have any information about the autopsy and histological results.

The images were assessed for the presence, severity, density, and composition of material in the airways in the larynx, trachea, main bronchi, and small bronchi up to the terminal bronchioles, in addition to the presence, severity, and distribution of lung density changes. Fluid in the large airways was considered blood when its density was measured to be between 40 and 60 Hounsfield Units (HU).

Images from series 1 and series 2 were examined to identify the source and, consequently, the mode (anterograde and/or retrograde) of blood aspiration.

The possibility of considering blood aspiration as the primary or contributing cause of death based on pulmonary CT images was also assessed, with consideration of the extent of density abnormalities within the entire pulmonary parenchyma. The lungs were also evaluated for the presence of any other deviations from normal imaging.

In one case, biopsy specimens from abnormal regions of the lungs were obtained for histological examination under CT fluoroscopy guidance using CAREVISION® software (Siemens), along with clinically approved, postmortem-tested ACN-III biopsy core needles (14 gauge × 160 mm) and an automatic pistol device (Bard Magnum; Medical Device Technologies, Stenløse, Denmark), according to the Virtopsy approach (32). After staining with hematoxylin and eosin, the slides were analyzed by a board-certified forensic pathologist.

Results

Autopsy

Table 2 shows the distribution and severity of blood or bloody fluids in the airways and the presence and severity of blood aspiration in the parenchyma. The hypothesized mode of blood aspiration is also indicated. There were 36 cases that showed autopsy evidence of bloody fluids in the respiratory tract between the larynx and the main bronchi. In 31 cases, aspiration was also observed in the lung parenchyma. Histological evidence of blood aspiration was documented in six of the 31 cases. Hemo-aspiration was not associated with traumatic lung injuries in 10 of the 31 cases, and a source of bleeding was found in the airways up to the small bronchi. Exclusively anterograde blood aspiration was assessed in these cases. In the remaining 21 cases, hemo-aspiration was related to traumatic pulmonary parenchymal lesions, although in eight cases (n. 01, 05, 07, 17, 19, 22, 25, and 29), the diagnosis was difficult to determine. In three of the 21 cases, the hemo-aspiration was considered to be exclusively retrograde; whereas in 18 of the 21 cases, a combined anterograde and retrograde mode was determined (Table 2). In one of the 37 cases, the aspiration was minimal (case n. 35), and in another, it was only evident histologically (case n. 33). The presence of lung hypostasis was a significant limitation in the autopsy examination of case n. 36.

Finally, blood aspiration was considered to be the primary cause of death in two cases (n. 15 and 23) and the contributing cause of death in four cases (n. 10, 18, 24, and 26) (Table 3).

CT Imaging

In 33 of the 37 cases, fluid content ranging from minimal to a massive amount was seen upon postmortem imaging of the respiratory tract between the larynx and the main bronchi (Fig. 1, Table 4). This fluid was considered to be blood in 21 cases (57%) based on the measured radiological density (range of densities in HU: 45–59) (Table 4).

Areas of lung parenchyma with a ground-glass appearance were observed in all cases. Those with a round shape and ill-defined edges were considered diagnostic of blood aspiration with different grading (Table 4). On the other hand, gradient densities were interpreted as internal hypostasis. Alveolar consolidations were observed at the posterior-basal edge (cases n. 10 and 18) and were attributed to small areas of atelectasis. No traumatic chest or pulmonary injuries were observed in 13 cases, but CT scan documented other

TABLE 2—*Presence of blood or bloody fluids on traditional macroscopic autopsy examination of airways and pulmonary parenchyma and on histological analysis of small bronchi and alveoli. The mode (anterograde and/or retrograde) of aspiration is also reported.*

Case Number	Larynx	Trachea	Main Bronchi	Small Bronchi	Pulmonary Surface and/or Cut Surface*	Pulmonary Histology†	Mode of Aspiration‡
01.	−	−	+/−	+/−	+	−	R
02.	+	+	+	+	+	−	A
03.	−	+/−	+	+	+	−	A-R
04.	−	+/−	+	+	+	−	A-R
05.	−	−	+/−	+/−	+	−	A-R
06.	−	+	+	+	+	−	A-R
07.	+	+	+	+	+	−	A-R
08.	−	+	+	−	−	−	/
09.	+	+	+	+	+	−	A-R
10.	−	+	+	+	+	−	A
11.	−	+/−	+/−	+/−	+	−	A-R
12.	−	+/−	+/−	+/−	+	−	A
13.	+/−	+/−	+/−	+/−	+	+	A-R
14.	−	+/−	+/−	+/−	+	−	A-R
15.	+	+	+	+	+	+	A
16.	+	+	+	+	+	−	A
17.	−	+/−	+/−	+/−	+	+	A-R
18.	−	+	+	+	+	−	A
19.	−	+/−	+/−	+/−	+	−	A-R
20.	−	−	−	−	+	−	R
21.	−	−	+	+	+	−	A
22.	−	+/−	+/−	+	+	−	A-R
23.	−	+	+	+	+	−	R
24.	−	+	+	+	+	+	A
25.	−	+	+	+	+	−	A-R
26.	+	+	+	+	+	−	A
27.	+	+	+	+	−	−	/
28.	−	−	+/−	+	+	+	A-R
29.	−	+	+	+	+	−	A-R
30.	−	−	+/−	+/−	−	−	/
31.	+	+	+	+	−	−	/
32.	+/−	+	+	+	+	−	A-R
33.	−	+	+	+	−	+	A-R
34.	−	+	+	+	+	−	A-R
35.	+/−	+/−	+/−	+/−	+/−	−	A
36.	−	+/−	+/−	+/−	−	−	/
37.	−	−	+/−	+/−	−	−	/

−, sign not recognized; +, sign recognized; +/−, sign recognized but of scant amount.
*Red, rounded areas with a patchy distribution.
†Presence of erythrocytes filling the smallest airways with intact walls.
‡A, anterograde; R, retrograde; A-R, mixed anterograde and retrograde; /, no evidence of aspiration.

TABLE 3—*Cause and manner of death for each case assessed by traditional techniques.*

Case Number	Cause of Death	Manner of Death
01.	Cerebral lesions	Suicide-FFH
02.	Brain stem laceration	Suicide-GW
03.	Cerebral lesions	Suicide-FFH
04.	Cerebral lesions, hemorrhage	Accident-RO
05.	Multiple injuries to thoracic	Accident-FFH
06.	Cerebral lesions, hemorrhage	Accident-RO
07.	Hemorrhage	Homicide-KSW
08.	Hemorrhage	Homicide-GW
09.	Cerebral lesions, hemorrhage	Accident-RO
10.	Blood aspiration, cerebral lesions, hemorrhage, brain stem laceration	Accident-FFH
11.	Brain stem laceration	Accident-FFH
12.	Brain stem hemorrhage	Accident-RO
13.	Hemorrhage	Accident-RO
14.	Brain stem laceration	Accident-RO
15.	Blood aspiration	Homicide-GW
16.	Cerebral lesions	Homicide-BI
17.	Cerebral lesions, hemorrhage	Accident-FFH
18.	Blood aspiration, hemorrhage	Suicide-GW
19.	Brain stem laceration	Accident-RO
20.	Hemorrhage, heart tamponade	Homicide-KSW
21.	Brain stem hemorrhage	Accident-RO
22.	Brain stem hemorrhage	Accident-RO
23.	Blood aspiration	Natural death-PT
24.	Blood aspiration, gas embolism	Accident-RO
25.	Heart laceration, hemorrhage	Accident-FFH
26.	Blood aspiration, hemorrhage	Natural death-LT
27.	Cerebral lesions, hemorrhage	Suicide-FFH
28.	Cerebral lesions, hemorrhage	Suicide-FFH
29.	Cerebral lesions, hemorrhage	Suicide-FFH
30.	Brain stem hemorrhage	Accident-RO
31.	Hemorrhage, gas embolism	Suicide-GW
32.	Cerebral lesions	Accident-FFH
33.	Hemorrhage	Homicide-GW
34.	Hemorrhage	Homicide-GW
35.	Brain stem laceration	Suicide-GW
36.	Brain stem laceration	Suicide-GW
37.	Brain stem hemorrhage	Accident-RO

FFH, fall from height; GW, gunshot wound; RO, rolled-over; KSW, knife/stub wounds; BI, blunt injuries; PT, pulmonary tumor; LT, laryngeal tumor.

possible sources of bleeding in the airways. Thus, an exclusively anterograde mode of blood aspiration was determined for these cases (Fig. 2). The distribution and severity of blood aspiration was also studied in these cases using 2D and 3D reconstructions (Fig. 3). In 4 of the 13 cases, the blood aspiration was determined to be minimal (Fig. 4, Table 4).

The remaining 24 cases showed lacerations, contusions, subpleural hematomas, pneumothorax, and/or hemothorax (Fig. 5). Of these cases, 21 had injuries (e.g., fractures of the skull base, tracheal lacerations) as possible causes for anterograde aspiration. There were also bloody fluids in the extrapulmonary airways in 12 of these cases. Among these 21 cases, both anterograde and retrograde modes of blood aspiration were hypothesized. In three cases, an exclusively retrograde mode of aspiration was determined (Table 4), while nine cases (n. 01, 05, 07, 08, 17, 19, 22, 25, and 29) showed diffuse damage to the lungs and thoracic structures, which made it more difficult to evaluate the ground-glass opacities and their relationship to blood aspiration. In all 24 cases, the distribution and severity of the nodular ground-glass opacities were not evaluated.

Based on the amount of blood or bloody fluids in the upper airways and the severity of changes in the parenchyma related to aspiration, blood aspiration was considered to be the primary cause of death by the radiologists in two cases (n. 15 and 23) and the contributing cause of death in six cases (n. 10, 12, 18, 21, 24, and 26).

Histological Examination of CT-Guided Biopsy Specimens

In case n. 37, hematoxylin- and eosin-stained needle biopsy specimens of imaging abnormalities suspected to be blood aspiration showed the presence of blood cells filling alveoli with intact walls (Fig. 6).

CT Imaging and Autopsy Comparison

Of the 36 cases with autopsy evidence of bloody fluids between the larynx and the main bronchi, 33 showed fluid material in the same respiratory tract on CT imaging. Case n. 20 showed an absence of blood in the airways by both methods. In the remaining three cases without radiological evidence of fluid material in the airways, two showed a minimal amount of bloody fluids at autopsy.

Regardless, CT imaging indicated a different amount of fluid than traditional techniques. In 21 of the 32 cases, the radiologically measured density was suggestive of a bloody composition, while in the other 11 cases, the minimal amount of fluid did not allow any determinations about its nature.

Of the 31 cases with pulmonary hemo-aspiration on macroscopic or microscopic examination, all had ground-glass opacities suggestive of blood aspiration upon pulmonary CT imaging (Tables 2–4). The CT scans were positive even when pulmonary blood aspiration was minimal (case n. 33 and 35) (Tables 2–4). In determining the mode of blood aspiration, both examination methods showed a mixture of anterograde and retrograde in 18 cases, only anterograde in 10 cases and only retrograde in three cases (Tables 2–4). In the

FIG. 1—*Extrapulmonary airway imaging features of blood aspiration. Transverse multislice computed tomography (MSCT) images at the level of (a) the laryngeal plane (case n. 12), (b) medial trachea (case n. 6), and (c) main bronchi (case n. 24) show filling-in of fluid.*

TABLE 4—*Presence and amount* of blood or bloody fluids on postmortem CT imaging of airways; signed ([a]) if the radiological density was measured and it was suggestive of blood/bloody fluids (Hounsfield Units range 40–60). Presence, severity[†] and distribution (DIS)[‡] of ground glass opacities (GG) and consolidations (CON) in lung parenchyma. In cases with associated thoracic/lung injuries, distribution of GG was nonassessed (/), because of their localization in the uninjured parenchyma close to lung lacerations and contusions.*

Case Number	Larynx	Trachea	Main Bronchi	Small Bronchi/Terminal Bronchioles	Lung Parenchyma GG/DIS	Lung Parenchyma CON/DIS	Mode of Aspiration[§]
01.	−	−	+/−	+	+, /	−	R
02.	−	+[a]	+[a]	+/−	+, PH-RL	−	A
03.	−	+[a]	+[a]	+/−	+, /	−	A-R
04.	−	−	+/−	+/−	+, /	−	A-R
05.	−	−	+/−	+/−	+, /	−	A-R
06.	−	+[a]	+[a]	+	+, /	−	A-R
07.	+/−	+/−	+/−	+	+, /	−	A-R
08.	−	+[a]	+[a]	+	+, /	−	A-R
09.	+/−	+[a]	+[a]	+	+, /	−	A-R
10.	−	+/−	+/−	+/−	++, D	+/−, B-POS-LL	A
11.	−	−	+/−	+/−	+, /	−	A-R
12.	+[a]	+[a]	−	+/−	+, D	−	A
13.	+/−	+/−	+/−	+/−	+, /	−	A-R
14.	−	−	+/−	+/−	+, /	−	A-R
15.	+/−	+/−	+/−	+	+, D	−	A
16.	−	−	+/−	+/−	+, A-ANT	−	A
17.	−	+[a]	+[a]	+	+, /	−	A-R
18.	−	−	+[a]	+	++, D	+/−, B-POS-RL	A
19.	−	+/−	+[a]	+/−	+, /	−	A-R
20.	−	−	−	+	+, /	−	R
21.	−	−	+[a]	+	+, D	−	A
22.	−	+[a]	+[a]	+	+, /	−	A-R
23.	+	+[a]	+[a]	+	+, /	−	R
24.	−	+[a]	+[a]	+	+, D	−	A
25.	−	+[a]	+/−	+	+, /	−	A-R
26.	+/−	+[a]	+/−	+	+, D	−	A
27.	−	−	+[a]	+	+, /	−	A-R
28.	−	−	+/−	+/−	+, /	−	A-R
29.	−	−	−	+/−	+, /	−	A-R
30.	−	−	−	+/−	+/−, PH-POS-RL	−	A
31.	−	+[a]	+/−	+/−	+/−, PH-RL	−	A
32.	−	+/−	+/−	+	+, /	−	A-R
33.	−	−	+[a]	+	+, /	−	A-R
34.	−	+[a]	+[a]	+	+, /	−	A-R
35.	−	+/−	+[a]	+	+/−, A-PH, LL	−	A
36.	−	−	−	+/−	+/−, A-PH-B-POS-LL	−	A
37.	+/−	+[a]	+[a]	+	+, /	−	A-R

*−, sign not recognized; +, sign recognized; +/−, sign recognized but of scant amount.
[†]Presence and grading of ground glass opacities: +/−, scarce ground glass opacities; +, diffused ground glass opacities; ++, some areas of consolidation also present. Presence and grading of alveolar consolidations: −, no consolidation; +/−, some areas of alveolar consolidation.
[‡]Predominantly apical (A), perihilar (PH), basilar (B), anterior (ANT), or posterior (POS) of the supine position, in left lung (LL) or in the right lung (RL). Alterations diffused to all parenchyma (D).
[§]A, anterograde; R, retrograde; A-R, mixed anterograde and retrograde.

10 cases with exclusively anterograde hemo-aspiration determined by autopsy, 2D and 3D imaging reconstructions (Fig. 3) allowed for a more detailed characterization of the extent and distribution compared to traditional techniques.

In the remaining six cases, CT images showed pulmonary abnormalities suggestive of hemo-aspiration that were not mentioned in either the autopsy report or the histological examination. In three of these six cases, the mode of aspiration was determined from CT images to be anterograde and of minimal severity; in the other three cases, combined anterograde and retrograde aspiration was determined. Among these six cases, four showed a bloody nature of the fluids in the trachea and/or bronchi, as determined by measuring the radiological density.

In case n. 37, the suspicion of blood aspiration based on CT imaging findings was confirmed by histological analysis of CT-fluoroscopy-guided biopsy specimens. Blood was observed in alveoli with intact walls (Fig. 6).

In eight cases with diffuse damage to the lungs and thoracic structures, traditional and tomographic techniques presented the same difficulties in evaluating the presence of blood aspiration. In one additional case (n. 8), postmortem imaging showed the possible presence of areas of aspiration in the lung parenchyma that were not mentioned in the final autopsy report.

With regard to the determination of blood aspiration as the primary or contributing cause of death, CT imaging and autopsy were concordant in cases n. 15, 23, 10, 18, 24, and 26.

In two cases (n. 12 and 21), anterograde blood aspiration was determined to be a contributing cause of death based on CT imaging findings, despite the autopsy reports.

Discussion

As breathing may cease simultaneously with cardiovascular arrest or brain death, or cease after agonal respirations in the early

FIG. 2—*Pulmonary CT findings in a case (n. 21) with anterograde aspiration. A transverse multidetector CT image shows rounded areas of ground-glass opacity in both lungs and within the entire cross-sectional area (arrows).*

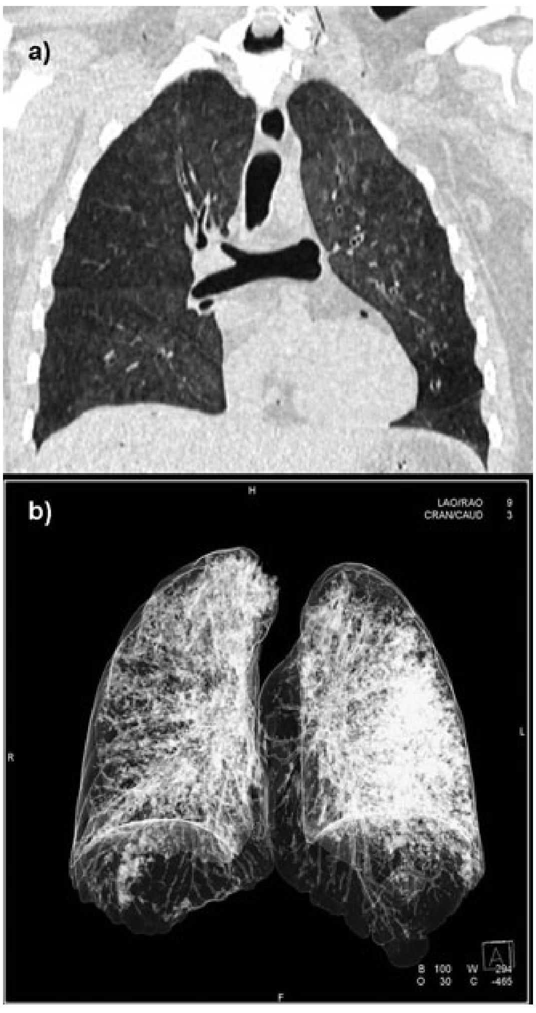

FIG. 3—*The distribution and severity of aspiration abnormalities in case n. 15 assessed by CT imaging. (a) 2D and (b) 3D volume-rendering images show multiple nodular ground-glass opacities distributed homogeneously in both lungs. In this case, blood aspiration was determined to be the primary cause of death by the radiologist.*

phase of cardiac arrest (33), the identification of blood aspiration can support forensic pathologists in assessing whether an injury occurred pre/peri- or postmortem. Moreover, the massive suction of blood into the deep respiratory tract may aid in the determination of the cause of death. Classically, lung and airway autopsy findings can aid in the diagnosis of retrograde blood aspiration or blood inhaled in an anterograde manner.

Modern cross-sectional imaging techniques are already considered to be reliable tools complementary to traditional forensic techniques (13–31). As early as the first publication from the Virtopsy project (13), Thali and collaborators suggested the superior sensitivity of MSCT imaging compared to traditional autopsy in detecting some signs of vital reactions (e.g., air embolism and aspiration), despite some limitations.

The present study was conducted in the Virtopsy research group and largely confirms the results obtained by Thali et al., especially with regard to blood aspiration (13). Furthermore, it provides additional data for the interpretation of imaging findings of hemo-aspiration as signs of a vital reaction and a cause of death.

According to clinical literature (34), CT abnormalities related to blood or bloody fluids in the bronchioles and the alveoli appear in multifocal, patchy areas of ill-defined ground-glass opacities, with a segmental distribution in the nondependent lung.

The gradient densities observed in the dependent lung are interpreted as internal hypostasis based on the position of the body (13,35,36).

The results of this work show a substantial concordance between postmortem CT and traditional techniques, with some exceptions that require explanation.

Airway analysis by CT was inferior to autopsy in assessing the presence and severity of aspirated blood, likely due to the minimal amount of fluid material in the respiratory tract to be detected and/or radiologically identified with confidence by HU measurement.

Pulmonary analysis by CT could be considered superior to traditional techniques in the six cases in which blood aspiration was determined contrary to autopsy findings (Tables 2–4). Traditionally, it is impossible to collect serial tissue samples for histological examination. In these six cases, CT images indicated anterograde aspiration of minimal severity in three cases and a mixture of anterograde and retrograde aspiration in the other three cases.

To confirm these results, a prospective study is necessary. Nevertheless, we are confident in concluding that in cases with minimal pulmonary blood aspiration or with associated blunt lung injuries, CT techniques can detect what may be missed on autopsy and histological examinations. Macroscopic findings of pulmonary hemo-aspiration may eventually be excluded when lung samples are retained for histological procedures or hidden by other traumatic pulmonary changes and postmortem artifacts. In case n. 36, sharp inner livores may have contributed to missing the diagnosis at autopsy. In contrast, CT images showed several round areas with ground-glass opacity (Fig. 4*b*).

We are also confident that CT imaging would be useful for cases in which hemo-aspiration is determined using traditional methods, because of the possibility of providing an exact distribution of the lung abnormalities with 2D and 3D reconstructions. The ability of CT to easily provide a visualization of the entire parenchyma can also avoid underestimation of the severity of pulmonary aspiration at autopsy. The diagnosis of fatal blood aspiration is usually confirmed by the histological demonstration of several alveolar groups filled with blood in the same visualization field. Histological examination of only a few slices of the lung tissue, however, could obscure information about the true extent and distribution of this phenomenon. Our study shows that this can be avoided by using CT imaging techniques.

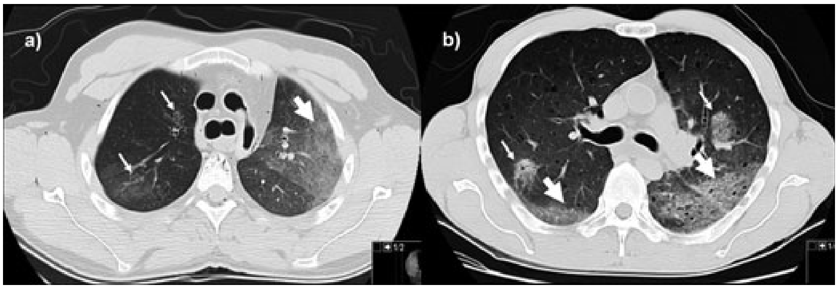

FIG. 4—*Pulmonary imaging findings in two cases (n. 33 [a] and n. 36 [b]) with anterograde aspiration of minimal severity. A transverse multislice computed tomography image shows rounded areas of ground-glass opacity in the right lung (a) and in both lungs (b) (thin arrows), associated with large homogeneous areas of increased density (bold arrows) in dependent regions. These were attributed to inner livores based on the position of the body after death. Note the greater density of gradient densities in the image in (b), which was obtained a longer period of time after death than the image in (a).*

FIG. 5—*Pulmonary imaging findings in a case (n. 4) with blunt thoracic injuries. A transverse multidetector CT image shows rounded areas of ground-glass opacity (thin arrows) close to lung lacerations (bold arrow) and contusions (arrowhead).*

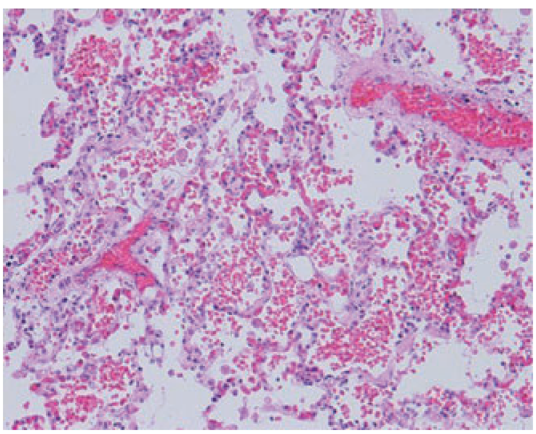

FIG. 6—*Histological findings from pulmonary samples of case n. 37 obtained by postmortem CT fluoroscopy-guided needle biopsy. A histological photograph (×10) of hematoxylin- and eosin-stained samples shows blood cells filling alveoli with intact walls.*

Thus, the determination of blood aspiration as the primary or contributing cause of death in cases of anterograde aspiration may be made more confidently by CT imaging than by histological examination.

Further considerations have to be made regarding the limitations of postmortem CT imaging in diagnosing the aspiration of blood or bloody fluids.

It is possible that fluid material of a different nature is aspirated (e.g., gastric content or water/blood mixture). Then, the ill-defined, rounded ground-glass opacities can also be radiologically detected, but according to clinical and postmortal radiology literature (13,34,37–45), they cannot be considered specific to the diagnosis of hemo-aspiration. This radiological condition also complicates distinguishing between pre- and postmortem pulmonary changes. The same lung pattern has been observed to be associated with minimal thickening of the alveolar interstitium or walls when a small amount of cells or fluid partially fills the alveolar spaces because of either fibrosis or inflammation (36).

We maintain that these limitations can be overcome by CT fluoroscopy-guided needle biopsy (Fig. 6). In case n. 37, given focused tissue sampling of the suspected areas of ground-glass opacity, this technique eliminated all doubt as to the presence of intra-alveolar blood (Fig. 6).

In conclusion, postmortem CT images of lungs and airways alone often do not offer enough data to distinguish with certainty lung findings because of blood aspiration from those because of other causes. Nevertheless, our results suggest that CT imaging should be considered a fundamental tool complementary to traditional autopsy techniques in forensic investigations of blood aspiration as a sign of a vital reaction or cause of death. This is based on its ability to detect small abnormalities related to blood aspiration, provide focused specimens for histological analysis, and guide forensic examiners in the inspection and sectioning of lung tissue for microscopic analysis. Moreover, 2D and 3D postmortem CT techniques can be considered as an excellent tool for analyzing the distribution of aspirated blood for documentation and the generation of powerful hypotheses regarding the cause of death.

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