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ORIGINAL ARTICLE

Postmortem CT versus forensic autopsy: frequent discrepancies of tracheobronchial content findings

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Abstract In their daily forensic casework, the authors experienced discrepancies of tracheobronchial content findings between postmortem computed tomography (PMCT) and autopsy to an extent previously unnoticed in the literature. The goal of this study was to evaluate such discrepancies in routine forensic cases. A total of 327 cases that underwent PMCT prior to routine forensic autopsy were retrospectively evaluated for tracheal and bronchial contents according to PMCT and autopsy findings. Hounsfield unit (HU) values of tracheobronchial contents, causes of death, and presence of pulmonary edema were assessed in mismatching and matching cases. Comparing contents in PMCT and autopsy in each of the separately evaluated compartments of the respiratory tract low positive predictive values were assessed (trachea, 38.2 %; main bronchi, 40 %; peripheral bronchi, 69.1 %) indicating high discrepancy rates. The majority of tracheobronchial contents were viscous stomach contents in matching cases and low radiodensity materials (i.e., HU<30) in mismatching cases. The majority of causes of death were cardiac related in the matching cases and skull/brain trauma in the mismatching cases. In mismatching cases, frequency of pulmonary edema was significantly higher than in matching cases. It can be concluded that discrepancies in tracheobronchial contents observed between PMCT and routine forensic autopsy occur in a considerable number of cases. Discrepancies may be explained by the runoff of contents via nose and mouth during external examination and the flow back of tracheal and main bronchial contents into the lungs caused by upright movement of the respiratory tract at autopsy.

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Abbreviations

CI	Confidence interval
FN	False negative
FP	False positive
HU	Hounsfield unit
NPV	Negative predictive value
PMCT	Postmortem computed tomography
PMI	Postmortem interval
PPV	Positive predictive value
ROI	Region of interest
TN	True negative
TP	True positive

Introduction

During the last 15 years, postmortem computed tomography (PMCT) has been established as a valuable adjunct to forensic autopsy. Meanwhile, relevant PMCT findings such as pathologic gas accumulations, fractures, and angiographic findings have been incorporated into the overall assessment of forensic cases [1–8]. In certain cases, authorities may even resign from

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traditional forensic autopsy and solely order forensic imaging, including PMCT [9–12]. In this context, it is of utmost importance for forensic radiologists and forensic pathologists to know how to interpret discrepancies between PMCT and forensic autopsy. The judgment of discrepancies between PMCT and autopsy may influence the interpretation of relevant forensic findings, especially when a forensic case is issued in court [1–4, 13]. Thus far, some substantial discrepancies between PMCT and forensic autopsy have been described in the literature. Schulze et al. showed that PMCT has a rather low sensitivity for detecting rib fractures compared to autopsy [14]. Roberts et al. revealed high discrepancy rates between PMCT and autopsy in terms of cause of death estimation especially in natural causes of death, such as sudden cardiac death or pulmonary embolism [15]. Filograna et al. observed discrepancies in tracheobronchial contents in some cases of relevant aspiration into the airways [16]. In their daily forensic autopsy casework, the authors of the present study found discrepancies in tracheobronchial content findings between PMCT and autopsy, not only in cases with relevant aspiration but also in cases without aspiration and to an extent not yet described in the literature. From the forensic point of view, the presence of tracheobronchial contents is highly relevant because it may be interpreted as a relevant forensic finding in terms of the estimation of lethal aspiration and aspiration as a sign of vitality. The goal of the present study was to evaluate discrepancies in tracheobronchial contents between PMCT and autopsy in forensic cases.

Materials and methods

Study subjects

Forensic autopsy cases (n=370) from a 12-month period at the Publications Host Institute were retrospectively enrolled for analysis of tracheobronchial contents in PMCT and autopsy. A total of 327 cases (121 female and 206 males with a mean age of 54±23) were included in this study. The exclusion criteria were severe injuries of the respiratory tract and signs of relevant decomposition according to autopsy reports. All cases underwent PMCT prior to forensic autopsy. Forensic autopsies were ordered by the local authorities. The use of the imaging data was approved by the local ethics committee. The postmortem interval (PMI, time between death and autopsy) ranged from 1 to 14 days.

CT scanning, image analysis, and HU measurements

The CT scanner was a Somatom Definition AS 64 (Siemens, Forchheim, Germany). Tube voltage was 140 kV. The corpses were placed in the supine position on the CT table for native CT scans. All scans were performed using an automatic dose modulation software (CARE Dose 4D, Siemens, Forchheim, Germany). Collimation was 64×0.6 mm. Image reconstructions were performed with a slice thickness of 1.0 mm and an increment of 0.7 mm using a soft tissue kernel (I31f) and a bone kernel (I70f). The field of view was adapted to the size of the object. Image analysis was performed on a regular radiological workstation (Leonardo, Siemens, Forchheim, Germany) by a radiologist blinded to the results of the autopsy. PMCT images were evaluated for contents in the trachea and bronchi. When present, tracheal and bronchial contents were measured in Hounsfield units (HUs). To obtain HU values, a total of five independent and nonoverlapping square regions of interest (ROIs) measuring fields were created in three different areas of the trachea and bronchi in which contents were detected in axial or sagittal CT images. The ROIs were placed over the entire ventro-dorsal expansion of tracheal or bronchial contents in axial or sagittal CT images. The sizes of the ROIs depended on the extensions of the tracheal or bronchial contents but were at least 4 mm in each dimension.

Autopsy and dissection of the respiratory tract

Autopsies were performed by board certified forensic pathologists immediately after PMCT scanning. The autopsy included external and internal examination according to the Recommendation of the Committee of Ministers to Member States of Europe on the harmonization of medico-legal autopsy rules [17]. All three body cavities were opened, and all organs were dissected. The respiratory tract was removed from the thoracic cavity and neck in one block (including tongue, larynx, trachea, and lungs) and was dissected ex situ on a plane dissection table with the posterior surface uppermost. Dissection of the respiratory tract started with opening the larynx at its posterior portion. Then, the trachea was opened longitudinally through the posterior membranous portion, and the main bronchi were pursued down to their entry into the lungs to the lobar and peripheral bronchi. The presence and characteristics of tracheobronchial contents were noted in the autopsy report. After opening of the trachea and bronchi, the lungs were dissected, retaining continuity with the trachea. Histological and toxicological examinations were not conducted regularly but only in particular cases according to case circumstances and autopsy results.

Comparison between PMCT and autopsy results

Autopsy reports of the 327 cases were evaluated for contents in the three anatomical compartments of the respiratory tract: trachea, main bronchi, and peripheral bronchi. This evaluation was performed by one observer blinded to the PMCT results. Afterward, the results from the autopsy reports were compared with those from the PMCT image analysis. The presence of contents in the trachea and bronchi, according to autopsy reports, were determined as gold standard. PMCT findings (also evaluated separately for trachea, main bronchi, and peripheral bronchi) were compared to autopsy findings after the following criteria: true positive (TP: match contents PMCT and autopsy, Fig. 1), false positive (FP: no match, contents in PMCT but not at autopsy), true negative (TN: match no contents), and false negative (FN: no match, contents at autopsy but not in PMCT). Tracheobronchial contents on PMCT but an only bronchial content at autopsy was defined as trachea FP and bronchus TP (Fig. 2). Contents in main bronchi and peripheral bronchi on PMCT but only peripheral bronchial contents at autopsy were defined as main bronchi FP and peripheral bronchi TP. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) with 95 % confidence intervals (CIs) were calculated separately for trachea, main bronchi, and peripheral bronchi.

Causes of death, HU values, and presence of pulmonary edema

For matching and mismatching cases in trachea, main bronchi, and peripheral bronchi, the cause of death and the presence of pulmonary edema (macroscopic appearance: heavy, wet, and subcrepitant lungs with fluid accumulation, especially in the dependent, basal regions of the lower lobes; microscopic appearance: if microscopic analysis was conducted: engorged capillaries and filling of the intra-alveolar air spaces by a granular pink precipitate in HE staining) were evaluated according to the autopsy reports. Chi-squared test was used to investigate significant differences in the frequency of pulmonary edema between matching and mismatching cases. Mean HU values for matching and mismatching cases were calculated separately for the contents in trachea, main bronchi, and peripheral bronchi. Saphiro-Wilks test was performed to evaluate the normal distribution of the HU values. A t test for paired samples was applied to test for significant differences between groups. For chi-squared test and t tests, p values <0.05 were considered statistically significant. All statistical analysis was conducted using SPSS (IBM Corp., Armonk, NY).

Results

Matches and mismatches of tracheal and bronchial content findings

In all cases with contents in the trachea and/or the main bronchi in PMCT, such contents were also apparent in the affiliated lower parts of the airways to the peripheral bronchi. There was no case in which tracheal and/or bronchial contents were present at autopsy but not in PMCT. Table 1 gives an overview of the quantities of matches and mismatches in PMCT compared to autopsy. In each of the separately evaluated compartments of the respiratory tract (trachea, main bronchi, peripheral bronchi), sensitivities and NPVs were 100 %, whereas specificities and PPVs were low indicating high discrepancy rates between PMCT and autopsy. An increase of PPV was observed from the proximal to the peripheral airways, indicating that discrepancies are more likely to be found in the trachea than in the peripheral bronchi.

Type of tracheal and bronchial contents and HU values

Figure 3 shows that in the matching cases, the majority of contents were thick stomach contents followed by blood and low-viscosity fluid material in all groups. In mismatching cases, the majority of contents had a mean radiodensity smaller than 35 HU, followed by those with higher mean radiodensities. Figure 4 depicts the mean HU values for matching and mismatching cases for trachea, main bronchi,

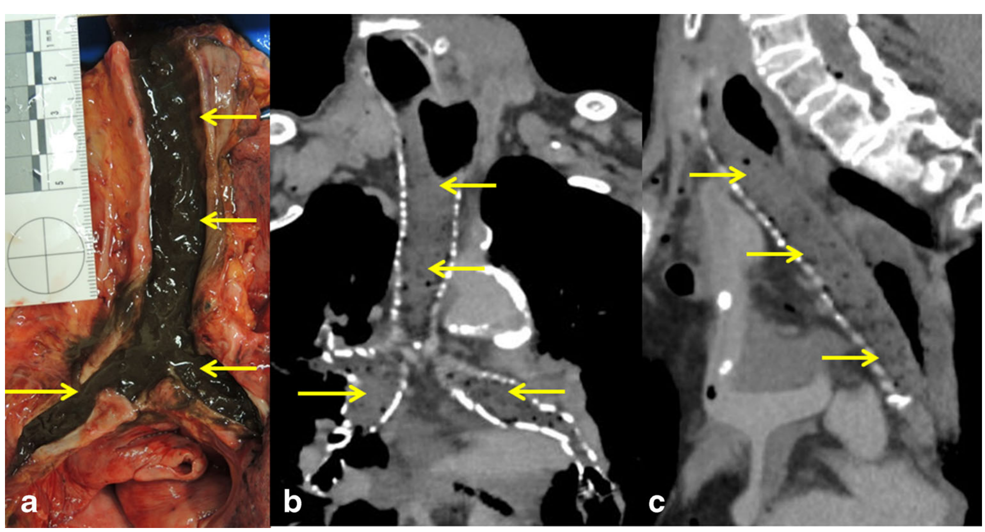

Fig. 1 Matching case of aspirated thick stomach contents in the trachea and main bronchi (*yellow arrows*) seen at autopsy (**a**) and in coronary and sagittal planes seen in PMCT (*yellow arrows*, **b**, **c**)

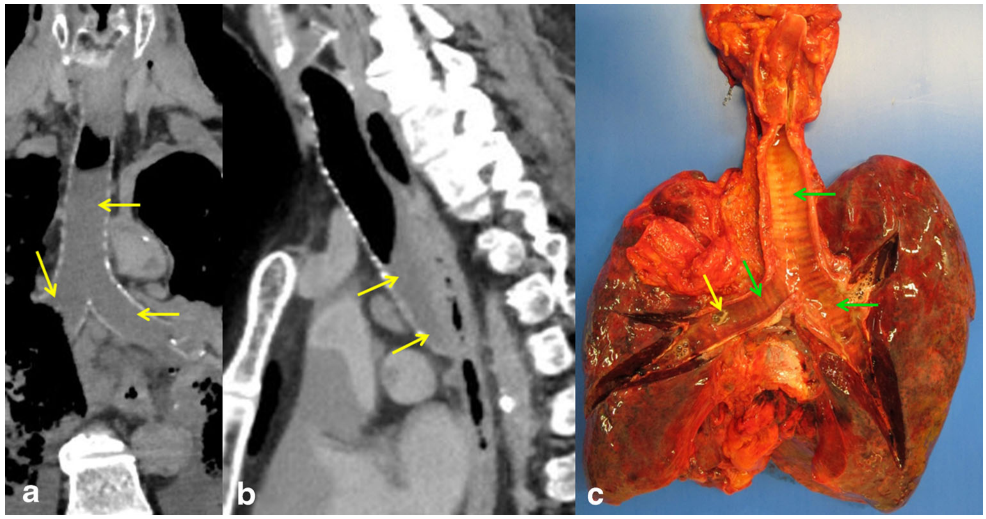

Fig. 2 Mismatching case of contents at the tracheal and main bronchial level in PMCT compared to autopsy. Note that while there are visible contents (*yellow arrows*) in the trachea and main bronchi in the coronary and sagittal planes in PMCT images (**a**, **b**), there are no contents (*green arrows*) in the trachea and main bronchi at autopsy of the partially dissected respiratory tract (**c**). Fluid content is visible in the left superior lobar bronchus (*yellow arrow*, **c**)

and peripheral bronchi. HU values were normally distributed in all tested groups. *t* Testing revealed significant differences between the HU values of matching cases compared to mismatching cases in each group ($p<0.05$ in trachea, main bronchi, and peripheral bronchi). In matching cases, higher maximum HU values up to 85 HU were observed. Minimal HU values down to 2 HU were apparent both in matching and mismatching cases in all groups.

Causes of death

Table 2 lists the causes of death for matching and mismatching cases evaluated separately in trachea, main bronchi, and peripheral bronchi. The majority of causes of death in mismatching cases were cardiac-related deaths, while in matching cases the majority of causes of death were traumatic skull/brain injuries. Aspiration (of foreign material, blood, or stomach contents) and drowning (in freshwater) were only causes of death in matching cases. A total of 16 drowning cases were assessed. All cases presented with high amounts of low-viscosity fluid materials in the trachea and bronchi according to autopsy reports.

Presence of pulmonary edema

Table 3 shows that chi-squared test revealed significantly higher frequencies of pulmonary edema in mismatching cases in trachea, main bronchi, and peripheral bronchi compared to matching cases.

Discussion

The rather high rate of discrepancies of tracheal and bronchial contents between PMCT and autopsy evaluated in the present study has thus far not been described in the literature and needs to be explained. In the study sample, discrepancies mainly occurred when tracheobronchial contents had low viscosity or low radiodensity, respectively. On the contrary, highly viscous tracheobronchial contents with elevated radiodensity showed concordant findings between PMCT

Table 1 Evaluation of tracheobronchial contents in PMCT compared to autopsy

	TP (match)	FP (no match)	TN (match, no contents)	FN (no match, contents at autopsy only)	Sensitivity in % (CI)	Specificity in % (CI)	PPV in % (CI)	NPV in % (CI)
Trachea	58	94	175	0	100 (100–100)	65.1 (59.4–70.8)	38.2 (30.4–45.9)	100 (100–100)
Main bronchi	74	111	142	0	100 (100–100)	56.1 (50.0–62.2)	40.0 (32.9–47.1)	100 (100–100)
Peripheral bronchi	141	63	123	0	100 (100–100)	66.2 (59.3–72.9)	69.1 (62.8–75.5)	100 (100–100)

Evaluation was performed separately for trachea, main bronchi, and peripheral bronchi. Note the low positive predictive value especially in the trachea indicating high discrepancy rates between PMCT and autopsy

PPV positive predictive value, *CI* confidence interval, *TP* true positive, *FP* false positive, *TN* true negative, *FN* false negative, *NPV* negative predictive value

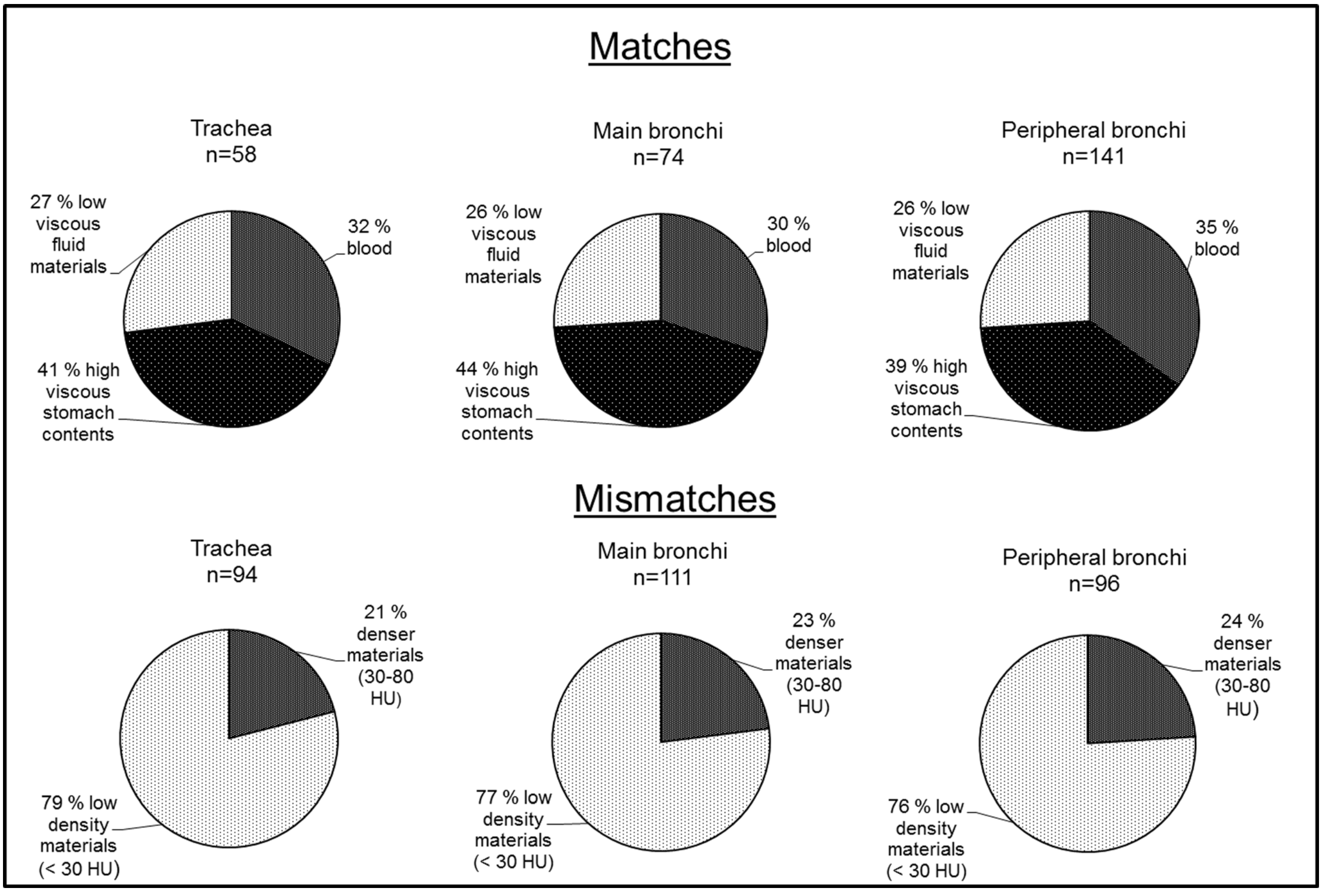

Fig. 3 Type of tracheal and bronchial contents in PMCT compared to autopsy according to autopsy reports in matching cases and HU values of contents in mismatching cases evaluated separately for trachea, main bronchi, and peripheral bronchi

and autopsy. These findings indicate that discrepancies may be related to the type of tracheobronchial contents. In this context, discrepancies may partially be explained due to movement of the corpse causing movement of contents within the respiratory tract. If the external examination of the corpse, which usually includes turning the body to analyze the backside, is conducted after PMCT, tracheobronchial contents may runoff via the nose and mouth (Fig. 5) and may therefore not be found during dissection of the airways. This finding is more likely to occur with low-viscosity contents, which flow out more easily than viscous contents due to their physical properties. A further reason for the observed discrepancies may be the technique of dissection of the respiratory tract at autopsy. In the authors' institute, the respiratory tract is removed from the thoracic cavity and neck as an organ/tissue block including the larynx, the trachea, and the lungs (Fig. 2c). This autopsy technique is well established and, to the best of the authors' knowledge, is conducted in most forensic institutes [18, 19].

Fig. 4 Ranges (mean, minimum, and maximum) of HU values in matching and mismatching cases evaluated separately for tracheal and bronchial content findings in PMCT compared to autopsy. Note that matching cases exhibit higher mean and maximum HU values. Contents with HU values near zero were assessed in all groups

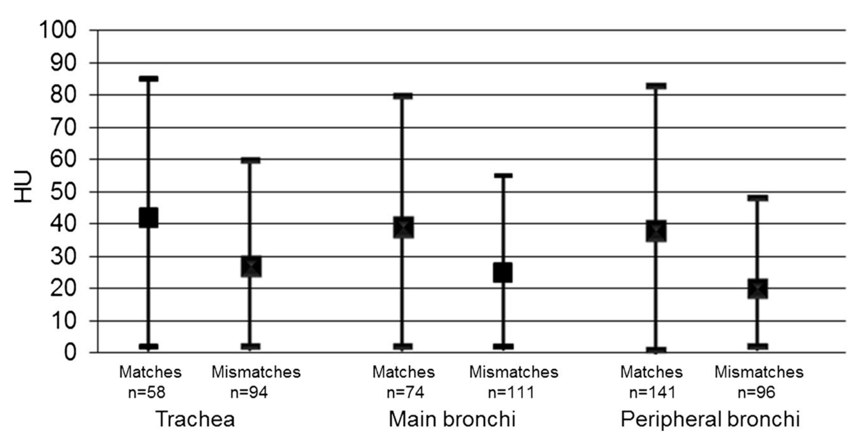

Table 2 Causes of death in matching and mismatching cases evaluated separately for trachea, main bronchi, and peripheral bronchi

Trachea			Main bronchi			Peripheral bronchi		
Matches (n=58)			Matches (n=74)			Matches (n=141)		
Causes of death	n	%	Causes of death	n	%	Causes of death	n	%
Skull/brain trauma	20	34.5	Skull/brain trauma	27	36.5	Skull/brain trauma	48	34
Drowning	12	20.7	Drowning	14	18.9	Cardiac arrest	33	23.4
Aspiration	8	13.9	Aspiration	11	14.9	Aspiration	16	11.3
Cardiac arrest	6	10.3	Cardiac arrest	8	10.8	Drowning	16	11.3
Intoxication	6	10.3	Intoxication	8	10.8	Intoxication	16	11.3
Exsanguination	4	6.9	Exsanguination	4	5.4	Exsanguination	9	6.4
Respiratory failure	2	3.4	Respiratory failure	2	2.7	Respiratory failure	2	1.4
						Pneumonia	1	0.7
Mismatches (n=94)			Mismatches (n=111)			Mismatches (n=96)		
Causes of death	n	%	Causes of death	n	%	Causes of death	n	%
Cardiac arrest	51	54.3	Cardiac arrest	61	55	Cardiac arrest	50	52.1
Skull/brain trauma	16	17	Skull/brain trauma	19	17.1	Intoxication	17	17.7
Intoxikation	13	13.8	Intoxication	16	14.4	Skull/brain trauma	14	14.6
Pneumonia	7	7.4	Pneumonia	8	7.2	Pneumonia	8	8.3
Exsanguination	4	4.3	Blunt abdominal trauma	3	2.7	Blunt abdominal trauma	3	3.1
Blunt abdominal trauma	3	3.2	Exsanguination	4	3.6	Exsanguination	2	2.1
						Respiratory failure	1	1
						Positional asphyxia	1	1

Note that in matching cases, the majority of causes of death were skull/brain trauma. In mismatching cases, the majority of causes of death were natural cardiac-related deaths. Lethal aspiration and drowning only appeared in matching cases

The use of this technique generally prevents the runoff of tracheobronchial contents via the upper airway openings. However, during removal from the thoracic cavity, the lungs and the trachea have to be lifted upright, as shown in Fig. 5b. It is assumed that during the lift of the respiratory tract, relevant amounts of tracheobronchial contents can flow back into the peripheral bronchi and the lungs. Therefore, the contents may vanish from the trachea and/or larger bronchi at dissection of the airways on a plain dissection table. The assumed flow back mechanism may account especially for low-viscosity materials. Nevertheless, there were 16 drowning cases with high amounts of low-viscosity tracheobronchial contents described in autopsy reports that presented with a match between PMCT and autopsy. It can be assumed that if high amounts of low-viscosity tracheobronchial content are present, such contents cannot flow back from the trachea or main bronchi into the lungs that are already filled and congested with fluid material. If high amounts of low-viscosity materials are present, they may also not entirely flow out via the nose and mouth while moving the corpse and, therefore, may still be visible to some extent at dissection of the respiratory tract.

As an interesting finding, the majority of mismatching cases presented with cardiac-related natural causes of death without relevant aspiration, while the majority of causes of death in matching cases were skull/brain trauma. Moreover, there was a lower incidence of lung edema in matching cases. The occurrence of mismatches between PMCT and autopsy in cases without aspiration at autopsy may be explained by

Table 3 Results of the chi-squared test to investigate differences in the frequency of pulmonary edema between matching and mismatching cases

	Trachea		Main bronchi		Peripheral bronchi	
	Match (n=58)	Mismatch (n=94)	Match (n=74)	Mismatch (n=111)	Match (n=141)	Mismatch (n=96)
Pulmonary edema (% of n)	34 (59)	85 (90)	46 (62)	88 (79)	83 (59)	79 (82)
p Value	<0.001*	<0.05*	<0.001*			

Note that in mismatching cases, the frequency of pulmonary edema was significantly higher than that in matching cases

*Statistically significant

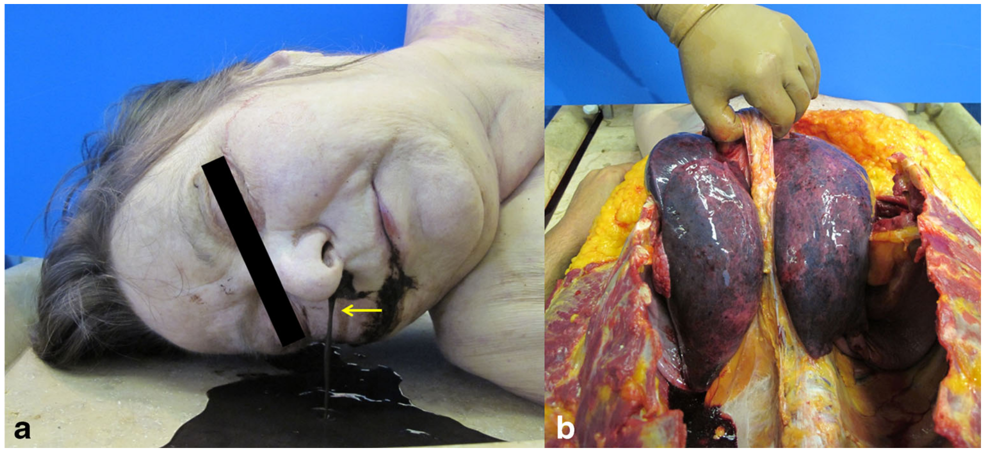

Fig. 5 Possible explanations for the mismatches of tracheobronchial contents between PMCT and autopsy may be the loss of contents during movement of the corpse at external examination (*yellow arrow*, **a**) and the backflow of low-viscosity material into the lungs at removal of the respiratory tract from the thoracic cavity, which normally includes uplifting the lungs along with the trachea (**b**)

pulmonary edema that often accompanies cardiac arrest [20–23]. Pulmonary edema fluid usually is rather poorly viscous in nature. In many cardiac-related deaths, the perimortal and/or postmortal redistribution of low-viscosity edema fluid from the lungs to the main bronchi and the trachea due to horizontal positioning of the corpse may explain the presence of tracheobronchial contents visible in PMCT but not at autopsy according to the above-discussed mechanisms. However, pulmonary edema frequently occurs in skull/brain trauma, which also represented the major cause of death in matching cases [24–26]. Hence, skull/brain trauma is also often associated with aspiration of blood or stomach contents. Stomach contents that contain thick and coagulated blood are rather viscous materials that are less sensitive to movement of the corpse and upright lifting of the respiratory tract, which may explain skull/brain trauma as the major cause of death in matching cases. Forensic pathologists and forensic radiologists should be aware that in cases with pulmonary edema, tracheobronchial contents in PMCT may be the cause of redistribution of low-viscosity edema fluid from the lungs to the main bronchi and the trachea. In such cases, redistributed edema fluid may be misinterpreted as aspirated material by the image reader.

In general, interpretation of tracheobronchial contents in PMCT is challenging. The PMCT image reader may want to determine the nature of tracheobronchial contents and interpret their forensic relevance in terms of the estimation of lethal aspiration and aspiration as a sign of vitality. The present study supports former research that found that measurements of the radiodensity of tracheobronchial contents with HU values can help determine the nature of the contents [10, 27, 28]. According to Zech et al., in PMCT, contents with HU values between 40 and 80 can be identified as blood. If HU values are between 0 and 35, the contents may be identified as serous fluids [5]. However, HU measurements do not reliably allow for determining the nature of tracheobronchial contents. Aspirated stomach contents of food components, for example, or aspiration of external foreign materials may possess radiodensity, which can mimic the HU values of blood or serous fluid materials [5, 10, 28]. Therefore, measurement of HU values alone does not allow for a safe discrimination between blood, serous fluids originating from lung edema, stomach contents, or other aspirated foreign material. However, the appearance of tracheobronchial contents in PMCT images may help discriminate between different types of tracheobronchial contents. Serous fluids and blood often exhibit a rather homogenous appearance in PMCT images. Blood may be sedimented and easy to recognize due to its two-layered appearance. On the contrary, aspirated stomach contents or aspirated viscous foreign materials such as mud appear rather inhomogeneous in PMCT images, as shown in Fig. 1b, c [5, 10, 27].

Limitations

The interpretation of PMCT images and measurements of HU values of tracheobronchial contents were conducted by only one observer. Therefore, interobserver error was not assessed.

The presence of pulmonary edema was assessed only according to autopsy reports and not according to PMCT findings because autopsy is the gold standard, and evaluation of edema in PMCT can be ambiguous due to postmortem changes such as internal livores.

The presence of fluid contents in the airways was not correlated with PMI. Ishida et al. demonstrated that in nontraumatic death cases, the appearance of fluid contents in the airways in PMCT correlated with the time after death [29]. Hyodoh et al. showed a decreased aerated lung volume due to fluid accumulations over time after death [30]. Therefore, in the present study, it may be possible that PMI may have had an influence on the presence of fluid contents in PMCT in the evaluated forensic cases. Hence, PMI might have had an influence on the extent of discrepancies of tracheobronchial content findings in PMCT compared to autopsy.

Conclusion

Discrepancies in the tracheobronchial contents between PMCT and forensic autopsy are a frequent finding and seem to occur to an extent previously unnoticed in the literature. A poorly viscous nature and low amounts of tracheobronchial contents may cause discrepancies, probably due to the runoff of contents via the nose and mouth during movement of the corpse and flow back of contents into the lungs due to upright movement of the respiratory tract at autopsy. Forensic pathologists and forensic radiologists should be aware that in cases with pulmonary edema, relevant amounts of tracheobronchial contents in PMCT may be the cause of redistribution of low-viscosity edema fluid from the lungs to the main bronchi and the trachea. In such cases, the contents may be misinterpreted as aspirated materials.

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