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# When gas analysis assists with postmortem imaging to diagnose causes of death

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ABSTRACT

Postmortem imaging consists in the non-invasive examination of bodies using medical imaging techniques. However, gas volume quantification and the interpretation of the gas collection results from cadavers remain difficult. We used whole-body postmortem multi-detector computed tomography (MDCT) followed by a full autopsy or external examination to detect the gaseous volumes in bodies. Gases were sampled from cardiac cavities, and the sample compositions were analyzed by headspace gas chromatography–mass spectrometry/thermal conductivity detection (HS-GC–MS/TCD). Three categories were defined according to the presumed origin of the gas: alteration/putrefaction, high-magnitude vital gas embolism (e.g., from scuba diving accident) and gas embolism of lower magnitude (e.g., following a traumatic injury). Cadaveric alteration gas was diagnosed even if only one gas from among hydrogen, hydrogen sulfide or methane was detected. In alteration cases, the carbon dioxide/nitrogen ratio was often >0.2, except in the case of advanced alteration, when methane presence was the best indicator. In the gas embolism cases (vital or not), hydrogen, hydrogen sulfide and methane were absent. Moreover, with high-magnitude vital gas embolisms, carbon dioxide content was >20%, and the carbon dioxide/nitrogen ratio was >0.2. With gas embolisms of lower magnitude (gas presence consecutive to a traumatic injury), carbon dioxide content was <20% and the carbon dioxide/nitrogen ratio was often <0.2. We found that gas analysis provided useful assistance to the postmortem imaging diagnosis of causes of death. Based on the quantifications of gaseous cardiac samples, reliable indicators were determined to document causes of death. MDCT examination of the body must be performed as quickly as possible, as does gas sampling, to avoid generating any artifactual alteration gases. Because of cardiac gas composition analysis, it is possible to distinguish alteration gases and gas embolisms of different magnitudes.



## 1. Introduction

Postmortem imaging examinations performed before autopsies are being used more frequently in forensic medicine [1,2]. Multidetector computed tomography (MDCT) is the most commonly used technique, notably because of its spatial resolution and high sensitivity, which enables the detection of small collections of gas in bodies that cannot be detected with standard autopsy techniques [3–5]. When investigating the cause of death, it is essential for the forensic pathologist to be able to distinguish between gas formed during postmortem cadaveric alteration and gas from a vital air embolism [6].

Decomposition carries many challenges for the forensic pathologist because findings that may have been discriminant for the diagnosis of cause of death may disappear with decomposition. Alteration is commonly encountered in forensic pathology practice and can result in the considerable distortion and modification of tissues [7]. Indeed, through postmortem microbial activity, decomposition and especially putrefaction induce gas generation. These gases are well identified in postmortem imaging, but they are rarely analyzed from a chemical point of view.

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Preliminary studies on one hundred bodies resulted in the development of a radiological alteration index (RAI) based on the volume and distribution of postmortem gases inside the body to estimate its radiological or internal alteration [8]. These studies showed that a body's external alteration does not necessarily correspond to its internal state of alteration. Indeed, a body may show no external signs of alteration but may already present some internal signs, such as gas formation. Cardiac and hepatic areas have been identified as important sites for the appearance of postmortem gas [9]. Nevertheless, gas analyses are essential because they provide crucial information, especially in the early stages of decomposition, to differentiate gas embolism from alteration gas and confirm the radiological diagnosis.

Indeed, gas embolisms of various magnitudes can be suspected on postmortem MDCT, but gas composition analysis is generally not systematically performed for routine cases [10,11]. This can lead to misinterpretations because of artifactual putrefaction gases that may arise owing to the postmortem delay. Therefore, based only on postmortem MDCT, a vital gas embolism may be falsely diagnosed after alteration has already begun and cannot be neglected [12]. Consequently, in those cases, gas analysis is not only a confirmatory tool but an obligatory one. Gas analysis should be mandatory when gas presence is detected by postmortem imaging in cases of suspected gas embolism [13] following traumatic injuries such as a gunshot to the head [14] or a scuba diving accident [15,16].

Gas analysis is not regularly used in forensic pathology to confirm a cause of death. The first studies in this domain were performed on rabbits [17] and later on rats [18]. These studies showed that the identification of hydrogen ($H_2$), hydrogen sulfide ($H_2S$) and methane ($CH_4$) are clear alteration indicators. If none of these gases is present, the ratio between carbon dioxide ($CO_2$) and nitrogen ($N_2$) can orientate a diagnosis toward embolism (if $CO_2/N_2 < 0.2$) or alteration (if $CO_2/N_2 > 0.2$) [19,20]. These results were recently confirmed on rabbits [21] and cetaceans [22] but rarely in humans [23,24].

Literature is scarce concerning human postmortem gas analysis. Moreover, the variability among the study results remains important, especially when decomposition has begun. First, animal studies cannot be effectively used because of the differences in the biochemical compositions of their bodies and their food habits compared with those of humans. Second, even among human bodies, gas composition may vary according to intrinsic parameters (blood loss, glycemic level, cachexia/obesity, hypothermia/pyretic state prior to death, etc.) and environmental conditions (ambient temperature, clothing, etc.). Finally, there is no standardized procedure of sampling and analysis. Imprecise tools, such as aspirometers [23–25], or techniques, such as sampling under water during autopsies, have been used. This technique can guarantee neither leaks of sampled gases nor the absence of contamination of the sampled gases by atmospheric air.

In this study, we aim to present the first results of gas analysis based on a harmonized protocol for sampling and analyzing postmortem gases in human bodies. The comprehension of gas composition will allow for the distinction between alteration gases and gas embolisms of different magnitudes.

## 2. Methods

### 2.1. Study design

This study was undertaken at the University Center of Legal Medicine in Lausanne between January 2012 and May 2014. We used whole-body postmortem MDCT to detect the presence of gaseous volumes inside cadavers. We prospectively assessed fifty-five cases, as shown in Fig. 1. The RAI was used to document the internal gas presence in each case [8]. The RAI value is based on the amount of gas present in seven defined anatomical sites (the left innominate vein, subcutaneous pectoral tissue, heart, liver, kidneys, abdominal aorta and vertebra L3). Gas quantity was assessed by a scoring system using four grades ranging from 0 to III: 0 for no gas, I for one to a few bubbles of gas, II for a structure partially filled with gas and III for a structure completely filled with gas. Using the statistical method of linear regression, each anatomical site was ponderated, using regression coefficients, with an adjustment to a total of 100. The RAI value therefore ranges from 0 to 100, from no gas to the extensive presence of gas in all tissues.

The main inclusion criterion for this study was the presence of a gas grade II or III in the heart. The study received ethical approval (Ethics Commission of CHUV, Lausanne, Switzerland). The study presented herein is focused on the analysis of cardiac gas and is part of a project aiming to monitor gases sampled from various sites.

### 2.2. The study population and groups

The bodies were divided into three groups according to their external alteration states, their causes of death and their RAI values. External examination of each body was performed by forensic pathologists, and postmortem MDCT was performed by forensic radiographers immediately after the external examination was complete to avoid any interference from biochemical modifications between the external examination and the MDCT. Fifteen bodies were used for training and protocol setting, and forty cases were used for the study, divided into three categories as presented in Table 1. After gas analysis was performed, the main exclusion criteria were $O_2$ percentage >15% with $CO_2/N_2$ ratio <0.2 throughout, suggesting possible ambient air contamination of a non-airtight sampling site (owing to decomposition, scavenging or trauma) or a leak during sampling. Based on exclusion criteria for possible contamination, seven bodies that showed cardiac gas compositions near that of the ambient air were excluded [22].

The validation process was performed in two steps. First, indicators were defined to identify the differences between and within groups (alteration states). Second, the validity of the previously determined indicators was checked by blinded analyses of multiple validation cases in each group.

**Group 1** included 3 cases with causes of death that were exclusively imputable to cardiac gas embolisms (E group). The embolisms were a pure gas embolism (PGE; perfusion accident E1) and a case of decompression compression sickness (DCS; diving accident E2). The validation case (E3) was a scuba diver with nitrox 32 (32% $O_2$, 68% $N_2$) used as the first diving gas from −6 m to −40 m, followed by air from −40 m to −80 m. The examination of the diving computer showed that approximately 40 min of decompression stops were lacking that would have avoided the DCS. Postmortem MDCT confirmed that all organs presented massive emphysema and that the cause of death was submersion in a DCS context.

**Group 2** included 4 cases with causes of death that were not specifically attributed to the detected gas embolism. The causes of death were mainly traumatic (T group) such as gunshot or sharp trauma (T1) or polytrauma (T2). The mechanisms and locations of the wounds induced gas penetration in the vessels, with magnitude depending on the nature of the injury. The two validation cases were a fall from a great height (polytrauma) (T3) and a case of craniocerebral trauma (gunshot) (T4).

**Group 3** included 26 cases for which external and radiological examinations indicated established cadaveric alteration. Three categories were defined in this group: beginning alteration (BA: 12 cases), moderate alteration (A: 8 cases) and advanced alteration