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TECHNICAL NOTE

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Visualization and Quantification of Air Embolism Structure by Processing Postmortem MSCT Data

ABSTRACT: Venous air embolism (VAE) is an often occurring forensic finding in cases of injury to the head and neck. Whenever found, it has to be appraised in its relation to the cause of death. While visualization and quantification is difficult at traditional autopsy, Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) offer a new potential in the diagnosis of VAE. This paper reports the findings of VAE in four cases of massive head injury examined postmortem by Multislice Computed Tomography (MSCT) prior to autopsy. MSCT data of the thorax were processed using 3D air structure reconstruction software to visualize air embolism within the vascular system. Quantification of VAE was done by multiplying air containing areas on axial 2D images by their reconstruction intervals and then by summarizing the air volumes. Excellent 3D visualization of the air within the vascular system was obtained in all cases, and the intravascular gas volume was quantified.

KEYWORDS: forensic science, forensic radiology, virtopsy, virtual autopsy, postprocessing, non-invasive autopsy, postmortem imaging, computed tomography, air embolism, imaging autopsy

Venous air embolism (VAE) is a frequent forensic finding in cases of injury to the head and neck (1–4). Depending on the air volume embolized, it may be the primary cause of death, an assisting or competing cause of death, or an accessory finding (5). Visualization and quantification at the autopsy room have been a great challenge through the past centuries and may not lead to satisfactory results. Opening the heart under water as well as performing traditional chest radiographs (1) failed in quantification. Elaborate methods using an aspirometer (6,7) could not reach widespread application.

Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) are becoming more widespread in postmortem evaluation. (8–11). The feasibility of VAE diagnosis by Multislice-Computed Tomography (MSCT) has already been shown (12). In this study, we describe the application of a processing software for CT data that achieves excellent three dimensional segmentation and visualization of the intravascular air.

Materials and Methods

Within the Virtopsy® project at the Institute of Forensic Medicine in Bern, 90 human corpses underwent combined MRI- and MSCT-examinations prior to autopsy from July 2000 until November 2003. Four of those 90 cases presenting with VAE (case 023 after a vehicle accident with massive head injury; cases 031, 072, and 073 with gunshot injuries to the head) were included to describe the findings of VAE and to test a postprocessing software specifically supporting the 3D presentation of air. The MSCT examination was performed on a scanner with 4 or 8 detector rows (Lightspeed QX/I, General Electric Co., Milwaukee, WI). Areas of forensic importance were scanned with a collimation of 4/8 × 1.25 mm. Up to 1200 axial cross-sections were calculated from the volume data, with adapted slice thickness and reconstruction intervals. The image acquisition time was 10 min. Processing of the acquired MSCT data was performed on a workstation (Advantage Windows 4.1, General Electric Co., Milwaukee, WI), using a volume rendering protocol for isolating air structures (voxtool 3.0.58d), which generates a 3D model of all gas-tissue borderlines within the scanned volume by the density differences. Quantification of the hemodynamic relevant air volume of cardiac cavities and pulmonary artery was obtained by multiplying areas of air-containing pixels of axial images by the reconstruction interval of 1.25 mm between contiguous images and adding all of these subvolumes. Traditional autopsy was performed by board-certified forensic pathologists.

Results

Figure 1 shows the 3D reconstruction of the air containing structures within the thorax using postmortem MSCT data and the air structure protocol in case 072. Virtual removal of both lungs reveals massive VAE of the right ventricle and the entire pulmonary trunk (Fig. 2). Further removal of the non-vascular structures containing air, such as the trachea, bronchi, esophagus, and spinal canal, allowed for an excellent visualization of the vessels involved by VAE (Fig. 3). Volume calculation revealed 58.5 mL of air within the right ventricle and pulmonary arteries. The location of the air within the vascular system depended on the position of the corpse during the terminal period and on individual anatomic and pathologic variants (Fig. 4). For example, after laceration of the lung or with a patent foramen ovale (case 031), the cavities of the left heart, the aorta,

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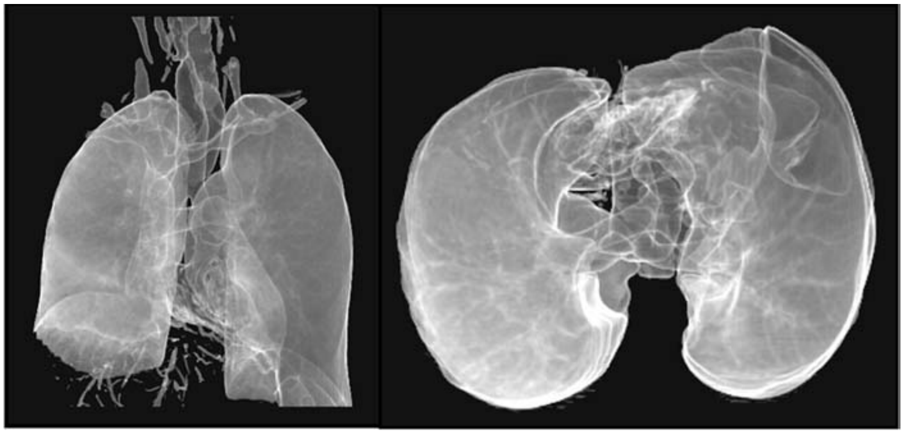

FIG. 1—*3D air structure reconstruction using MSCT data of the air filled spaces within the chest in case 072 (gunshot to the head); left: antero-posterior view, right: caudo-cranial view.*

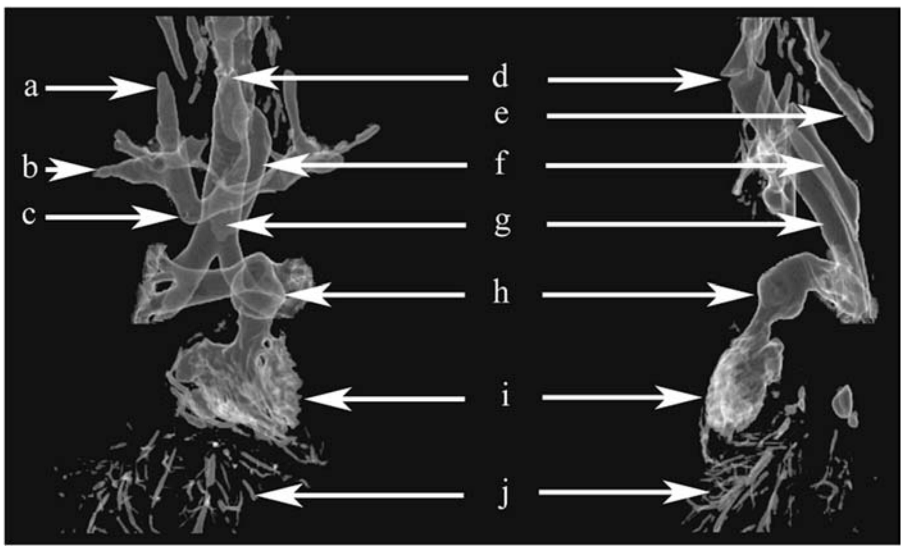

FIG. 2—*Air filled anatomical structures of case 072 after lungs have been virtually removed (left: antero-posterior view, right: lateral view):* (a) *right internal jugular vein;* (b) *right subclavian vein;* (c) *superior vena cava;* (d) *laryngeal cavity;* (e) *spinal canal;* (f) *oesophagus;* (g) *trachea;* (h) *pulmonary artery trunk;* (i) *right ventricle;* (j) *hepatic veins.*

and other systemic arteries appear on air structure reconstructions (Fig. 4*c*).

Discussion

The authors present a simple method for the detection, visualization, and quantification of air embolism in the deceased using postmortem MSCT and processing software. Its application is superior to the traditional methods in visualizing air embolism within the vascular system, and above all in quantifying it. MSCT represents an improvement in the postmortem evaluation of cases of suspected VAE. In contrast to Kauczor et al. (12), the authors did not reconstruct the air as a negative contrast agent but as the air-tissue borderlines in volume rendering technique and thereby reached an increased accuracy of visualization. No autopsy with modified technique will be necessary to prove VAE. Virtual quantification is easy; although there is no gold standard verifying it, its objective reproducibility is far superior to traditional subjective estimations. In the immediate future, MSCT will gain importance because it supports the decision about the relevance of detected VAE. Using routine postmortem MSCT examinations, VAE will likely be detected more often than at routine autopsies, as Mallach et al. (5) assumed many years ago. In comparison to the elaborate quantification methods of traditional autopsy (6), MSCT quantification of VAE is far faster. Its limitation clearly is the fact that MSCT nonspecifically detects any gas. Although the presented four cases did not show any signs of putrefaction by postmortem MSCT or by autopsy, putrefaction gas cannot be differentiated from VAE and will also appear in the presented reconstructions. To overcome this limitation, image-guided minimally invasive transthoracic puncture and gas chromatography may prove or refute the suspicion of relevant putrefaction gas (6,7,13).

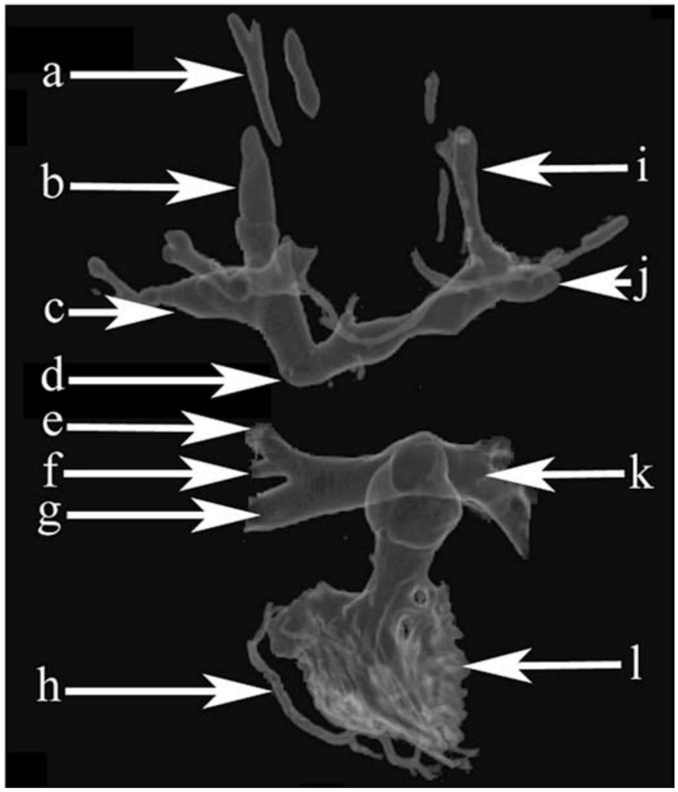

FIG. 3—*Case 072 when all air filled structures that do not belong to the vascular system are removed, resulting in a 3D reconstruction of all VAE parts caused by this head injury;* (a) *right external jugular vein;* (b) *right internal jugular vein;* (c) *right subclavian vein;* (d) *superior vena cava;* (e) *right upper lobe artery;* (f) *right middle lobe artery;* (g) *right lower lobe artery;* (h) *small cardiac vein;* (i) *left internal jugular vein;* (j) *left subclavian vein;* (k) *right pulmonary artery;* (l) *right ventricle.*

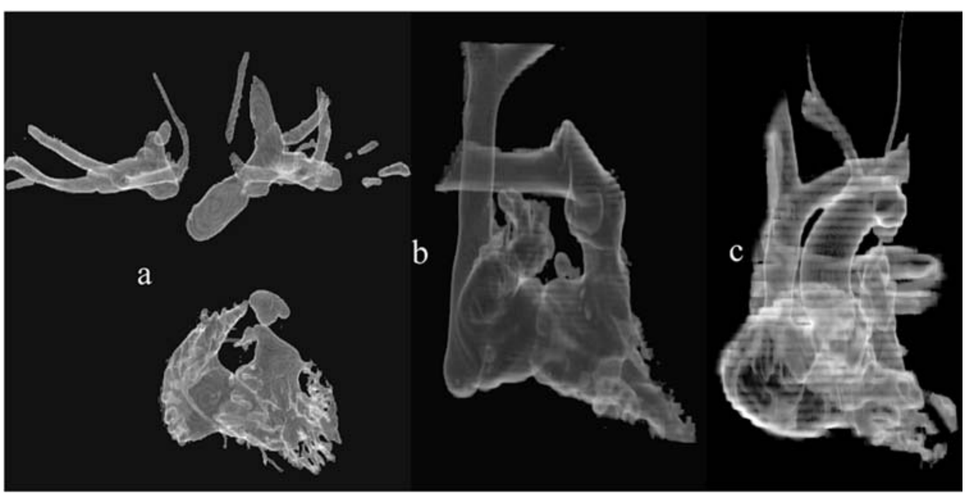

FIG. 4—(a) *3D air structure reconstructions in case 073 (gunshot to the head) enclosing 42.1 ml air within right atrium and ventricle and air filled veins of the upper thorax;* (b) *in case 023 (vehicle accident with massive head injury) enclosing 73.9 ml air within superior vena cava, right atrium, ventricle, and pulmonary artery; and* (c) *in case 031 (gunshot to the head) enclosing 214.5 ml air within superior vena cava, right atrium, ventricle, pulmonary artery and left atrium, ventricle, and aorta with patent foramen ovale.*

Conclusions

Postmortem MSCT data and processing software, as used in the Virtopsy approach, are highly accurate in detecting, visualizing, and quantifying air embolism. As in traditional autopsy, the detection of intravascular gas requires exclusion of putrefaction.

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