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PAPER

PATHOLOGY/BIOLOGY

Tony Fracasso,[1] *M.D.; Bernd Karger,*[1] *M.D., Ph.D.; Peter F. Schmidt,*[1] *M.D., Ph.D.; Wolf D. Reinbold,*[2] *M.D., Ph.D.; and Heidi Pfeiffer,*[1] *M.D., Ph.D.*

Retrograde Venous Cerebral Air Embolism from Disconnected Central Venous Catheter: An Experimental Model

ABSTRACT: There are few reported cases of death attributed to retrograde cerebral air embolism from central venous catheter. The pathophysiological mechanism and the necessary conditions are not fully understood, also because of missing experimental data. We performed experimental simulation while working on a possible case of retrograde cerebral air embolism. A hermetic system consisting of two containers connected to each other and to an electric pump by means of rubber hoses was built. In this system, a fluid (water and blood) could continuously flow under conditions similar to those of the common jugular vein. The part of the system representing the jugular vein could be freely positioned at angles between 0 and 90°. A central venous catheter was inserted into this part. After disconnection, the behavior of the air bubbles entering the hose through the tip of the catheter was evaluated at different positions. At angles between 0 and 45°, the air bubbles followed the fluid flow. At angles >45°, the air bubbles showed the tendency to flow upstream; this phenomenon was more evident the more vertically the hose was located. We were able to demonstrate that a retrograde air embolism can be caused by a disconnected catheter and is even more likely if the neck is in a vertical position.

KEYWORDS: forensic science, forensic pathology, case reconstruction, gas embolism, air embolism, retrograde cerebral air embolism, central venous catheter

The embolization of air bubbles is a known complication of many invasive medical procedures (1–4). If the entry site is a vein, the bubbles will flow with the blood into the right side of the heart where they are pushed further into the pulmonary artery. This can result in a progressive obstruction of the pulmonary circle, leading to acute right ventricular failure (5). If a right-to-left shunt is present (patent oval foramen, pulmonary artero-venous shunts), a paradoxal arterial air embolism with cerebral and cardiac damage may occur (5,6).

The case of a retrograde cerebral air embolism has been rarely reported (7–11). A recent observation of such a rare case motivated us to develop an experimental model to better understand its pathophysiology.

Case Report

A 62-year-old woman underwent a right hemicolectomy because of ischemic colitis. The operation and the first postoperative course were uneventful. Thirty-six hours later, while getting up from bed, the woman became suddenly dyspneic. She was suggested to lie down with elevated thorax. After an initial improvement of the respiratory symptoms, her condition rapidly deteriorated and she fell into a coma. A computed tomography (CT) scan revealed a massive gas embolism of the cerebral superficial veins (Fig. 1*a*). A second cerebral scan performed 2 days later revealed a massive edema with necrotic areas and a few small gas bubbles left in the venous system corresponding to venous infarctions (Fig. 1*b*). The woman's condition progressively deteriorated during the following 8 days with increasing cerebral hypertension and cerebral ischemia.

At external examination, the body was 165 cm tall and weighed 48 kg. A 2-lumen central venous catheter (eight French double lumen, 2 × 14 G.,×20 cm; Arrow Deutschland GmbH, Erding, Germany) was correctly placed in the right internal jugular vein and fixed to the skin through a catheter clamp. The proximal end of the catheter was connected to a 2-way infusion device, the distal end to a 4-way infusion device; all the screw plugs were firmly closed.

At autopsy, the brain showed a flabby consistency and a severe edema. It was immerged in 4% buffered formalin for later neuropathological investigation. Presence of air in the heart was evaluated as described elsewhere (12). In the right atrium and ventricle, 8 mL of gas could be collected. The left cardiac chambers did not contain any gas. The oval foramen was closed. Other pathological findings were the consolidation of the parenchyma of the inferior lobe of the right lung, chronic pulmonary emphysema, and a severe aorta coronary sclerosis.

At histology, the brain showed multiple infarctions ranging from fresh to subacute and a severe hypoxic–ischemic encephalopathy. A beginning bronchopneumonia at the right lung was confirmed.

On the basis of the clinical history and the macro-microscopic findings, the cause of death was a generalized cerebral ischemia following multiple infarctions because of retrograde gas embolism of unknown origin.

[1]Institute of Legal Medicine, University Hospital of Münster, Röntgenstr. 23, 48149 Münster, Germany.
[2]Institute of Diagnostic Radiology and Nuclear Medicine, Hospital Minden, Hans-Nolte-Straße 1, 32429 Minden, Germany.

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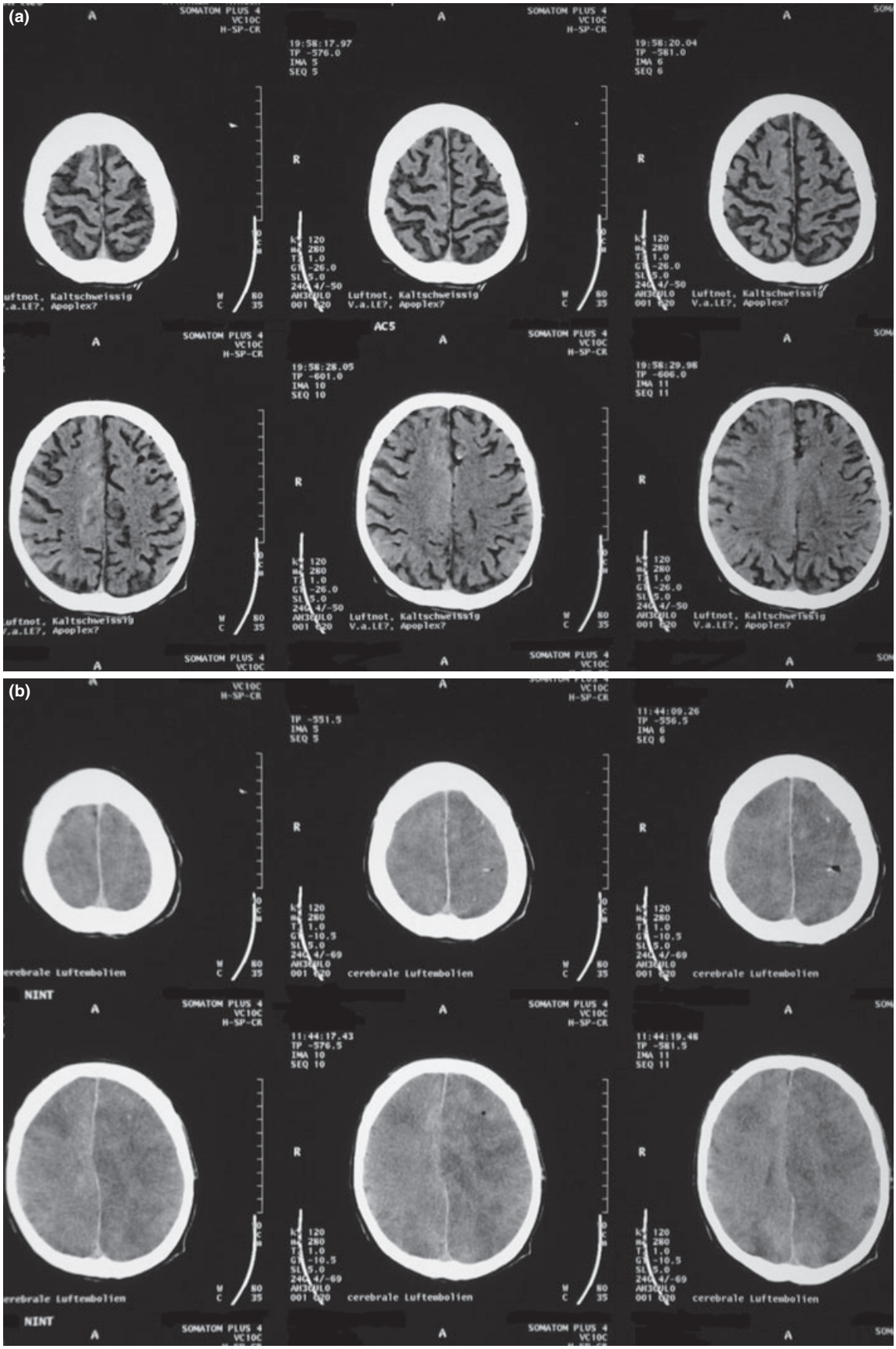

FIG. 1—*(a) Cerebral CT performed shortly after the beginning of the symptoms. Multiple air bubbles distending the superficial veins (in black) in the depth of the gyri and the bridging veins. (b) Two days later only few residual air bubbles could be detected (in black, visible in the image at the right side of the superior line and in the central one of the inferior line). The investigation showed severe edema and areas of necrosis corresponding to venous infarctions.*

The only possible source of air entry was the central venous catheter. A research of the literature confirmed the extremely rare occurrence of such a phenomenon (7–10).

Experimental Testing

After removal, the catheter was tested for eventual construction faults: the device was connected to a bedside monitor Sirecust 402 (Siemens, München, Germany), and air was pumped with a syringe into the catheter increasing pressure up to 350 mmHg. The pressure curve on the monitor showed a progressive increase: the system was hermetic.

The experimental system we used is a modified version of the one described by Schlimp et al. (7). It consisted of two transparent plastic containers connected to each other and to an electric pump by means of rubber hoses with an internal diameter of 11 mm (Fig. 2). The pump was regulated to allow experiments with a fluid flow of 0.2 and 0.5 L/min (velocity 3.5 and 8.8 cm/sec, respectively). The fluid (water and swine blood with citrate to avoid coagulation) could continuously flow under conditions similar to those of the internal jugular vein. The part of the system representing the jugular vein could be freely positioned at angles between 0 and 90°. An 8.5-French venous catheter (Arrowgard Blue with Arrowflex; Arrow Deutschland GmbH) was inserted downward into the hose and, after disconnection, the behavior of the air bubbles entering the hose through the tip of the catheter was evaluated at different positions with water and swine blood, at the two different flows.

At angles between 0 and 45°, no air bubbles entered the hose, independently of the fluid and the flow rate. At angles >45°, the air bubbles entered the hose and showed the tendency to flow upstream with a fluid flow of 0.2 L/min (Fig. 2*c*); this phenomenon was more evident the more vertically the hose was positioned, reaching the maximum at 90°. In contrast, at a flow of 0.5 L/min, all the bubbles entering the hose followed the fluid stream (Fig. 2*b*). No differences between water and blood could be observed.

Discussion

The phenomenon of air embolism is mainly known in legal medicine as a sign of vitality in cases of neck and head injuries (13,14) or possible complication of medical and surgical interventions (1,15–17). The rare possibility of a suicide or homicide by intravenous air injection has to be mentioned too (18,19).

Central venous catheters are a known potential source of air embolism (4,7,9). However, the occurrence of a retrograde venous

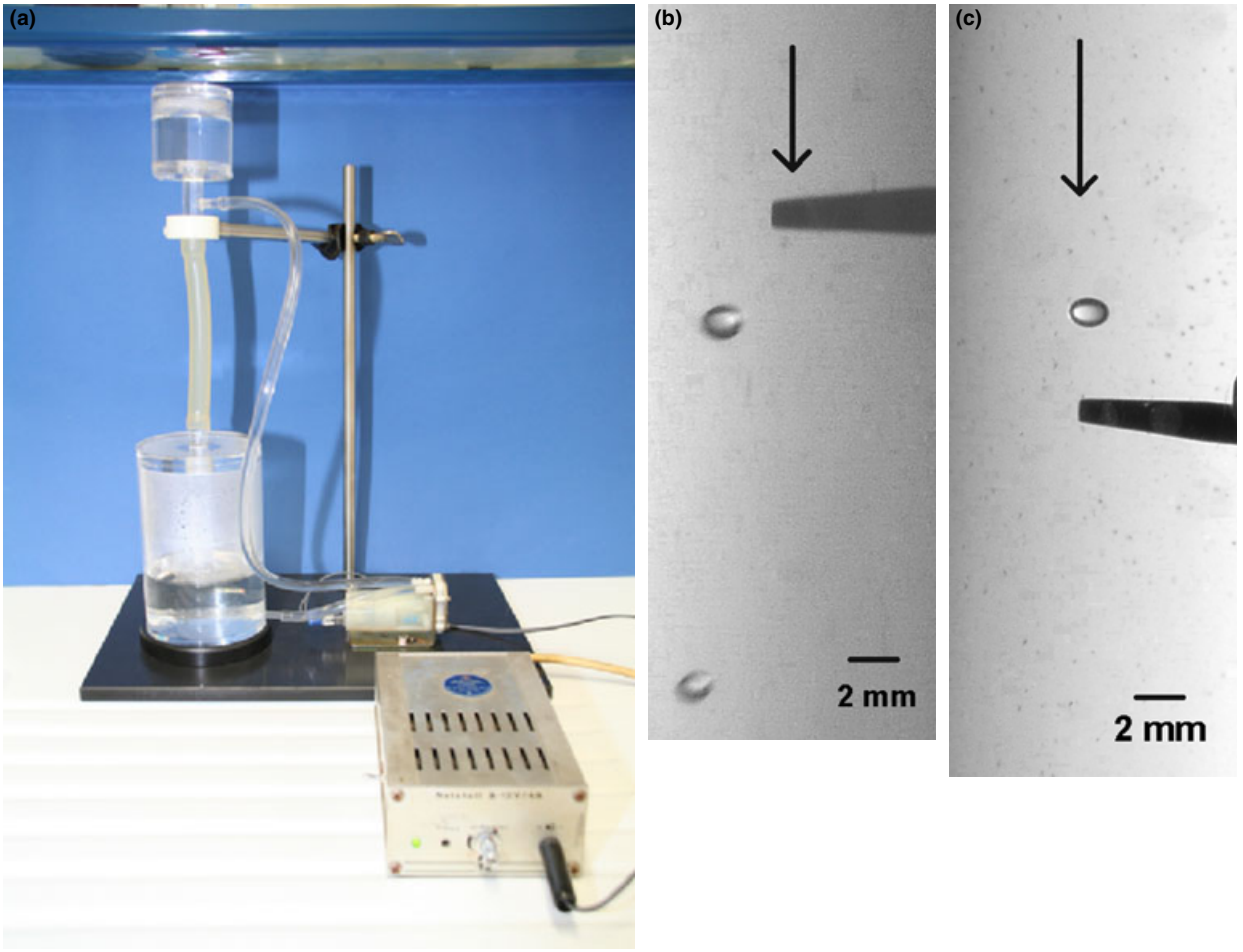

FIG. 2—*(a) In our experimental model, the internal jugular vein was represented by a rubber hose that could be positioned at different angles between 0 and 90°. The flow was determined by an electric pump. A central venous catheter was inserted into the rubber hose and left open. At angles between 0 and 45°, no air bubbles entered the hose. (b) At a flow of 0.5 L/min, all the bubbles entering the hose followed the fluid stream. The arrow indicates the stream direction. (c) At angles >45°, the air bubbles entered the hose and showed the tendency to flow upstream with a fluid flow of 0.2 L/min. The arrow indicates the stream direction.*

cerebral air embolism is not as well known and is probably underestimated (7). Schlimp et al. (7) experimentally demonstrated the possibility of retrograde embolism in a simulation with an angle of 90°. In our model, we could evaluate the influence of the inclination of the vein and could demonstrate, on the one hand, that at angles <45°, no embolism occurs independently of the kind of fluid or flow. On the other hand, air embolism occurs at angles >45°. The retrograde flow of air bubbles occurs at a flow of 0.2 L/min and is especially evident in proximity of the vertical position. At a flow of 0.5 L/min, no retrograde embolism was observed.

The accidental opening of a central venous catheter may determine the entry of air into the venous circle. Special conditions, such as the upright position of the thorax, forced expiration, cough, or Valsalva maneuver (8,20), facilitate the retrograde rising of air bubbles that accumulate into the cerebral venous system. A sudden loss of consciousness and the development of brain edema represent the most common clinical presentation. The CT scan demonstrates low-density areas within the intracranial venous system with involvement of the sagittal and cavernous sinuses. This finding can be misinterpreted thus leading to late diagnosis with lethal consequence: in the few cases cited in the literature the patients died.

In the nursing record of the case presented, we found a very precise description of the situation in which very likely the embolism occurred. A nurse was helping the woman who wanted to get up from a lying position when she suddenly turned dyspneic and cyanotic. As a reaction, the nurse suggested to lie down with elevated thorax. We suppose that at the moment when the patient tried to get up, the central venous catheter was already disconnected. Up to that moment, probably no air embolism had occurred because of the *c.* horizontal position of the neck. When the head was raised in an attempt to get up, a retrograde air embolism occurred. The reaction of the nurse, ideally correct in cases of dyspnea, in this specific case probably facilitated further embolism.

In this paper, we deliberately used the term "air" embolism. Indeed, the correct form should be "gas" embolism, as we did not perform any investigation to identify the composition of the gas collected from the heart. This kind of investigation plays a determining role in the differential diagnosis between real gas embolism and postmortem gas production from putrefaction (21,22). In our case, the gas embolism was diagnosed before death. The autopsy was performed 24 h after death on a well-refrigerated body: all these conditions make the postmortem production very unlikely. Anyway, should a postmortem production have occurred, its autopsy detection would have had marginal meaning without implications for the case.

From a medico-legal point of view, we can not exclude the occurrence of a suicidal or homicidal opening of the catheter or injection of air into the catheter. The criminal investigations performed by the police did not find any element to support this possibility.

This study is intended to give evidence to the less known phenomenon of retrograde venous cerebral air embolism from disconnected central venous catheters. The education of medical staff regarding this probably underestimated iatrogenic illness can easily lead to its decreasing prevalence because of frequent verifications of the central venous catheter and to faster diagnosis with immediate onset of the adequate therapy. The question of possible litigation for professional responsibility is still unclear because of the rare occurrence/identification of this phenomenon. However, it can be assumed that the increasing number of reports in the literature and the widening knowledge of this subject will determine, from one side, a minor occurrence and from the other one, the easier determination of professional guilt in cases of malpractice.

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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Additional information—reprints not available from author:
Tony Fracasso, M.D.
Institute of Legal Medicine
University Hospital Münster
Röntgenstr. 23, 48149
Münster
Germany
Email: Tony.Fracasso@hcuge.ch