Clinical Reports

Severe pulmonary oedema after venous air embolism

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We present a 59-yr-old Chinese male patient who developed acute pulmonary oedema and cardiovascular collapse following multiple episodes of venous air emboli while in the sitting position for removal of a cervical meningioma. The severity of the pulmonary oedema and cardiovascular disturbance were surprising. Postoperative ventilation and inotropic support were required and five litres of plasma were needed to replace the fluid lost as pulmonary oedema. We discuss the differential diagnosis of the pulmonary changes and review current ideas on the pathogenesis for pulmonary oedema following venous air embolism.

Un patient de 59 ans d'origine chinoise développe une oedème pulmonaire aigu et un collapsus vasculaire à la suite d'une série d'embolies gazeuses veineuses pulmonaires survenues pendant l'excision d'un méningiome cervical en position assise. La gravité de l'oedème pulmonaire et de ses conséquences hémodynamiques sont inhabituels et nécessitent la ventilation mécanique postopératoire et une médication inotrope. Cinq litres de plasma sont requis pour remplacer la perte de liquide par oedème pulmonaires. Nous discutons du diagnostic différentiel des affections pulmonaires et des théories actuelles sur la pathogénèse de l'oedème pulmonaire causé par l'embolie gazeuse.

Case report

A 59-yr-old, 64 kg Chinese male presented with progressive left-sided sensory loss and motor weakness. In-

vestigation revealed a dumb-bell shaped cervical meningioma at the C₂₋₃ level of the spinal cord. He had diabetes, well controlled by diet, and mild, untreated hypertension with evidence of left ventricular hypertrophy (LVH) and right bundle branch block (RBBB) on the electrocardiogram (ECG). Dexamethasone and ranitidine were started two days before the cervical laminectomy.

No premedication was given. Anaesthesia was induced with thiopentone 125 mg, fentanyl 300 µg and succinylcholine 100 mg. Following tracheal intubation, anaesthesia was maintained with nitrous oxide 70% and isoflurane 0.5–1% in oxygen, and an infusion of atracurium to maintain the post-tetanic twitch count less than five.¹ Monitoring consisted of ECG, pulse oximeter, central venous pressure (CVP), direct arterial pressure, oesophageal stethoscope, end-tidal carbon dioxide (PETCO₂), and urinary catheter. The central venous catheter (Cavafix 375: B Braun, Melsungen, Germany) was inserted through the right basilic vein and its position at the right atrium was confirmed subsequently by chest x-ray (CXR). Elastic stockings were used to minimize venous pooling. The patient was moved gradually to the sitting position. Normal saline (NS) 500 ml and stable plasma protein solution (SPPS) 500 ml were infused to maintain haemodynamic stability. Three hours after the start of surgery, during dissection of the dura, the PETCO₂ decreased from 34.5 mmHg to 28.5 mmHg over 30 sec without any change in arterial pressure, heart rate, minute volume or airway pressure. Bilateral neck compression was performed and the inspired oxygen fraction (FiO₂) increased to 1.0. There was no air aspirated from the central line and no site of air entrainment could be found. The PETCO₂ gradually returned to normal over five minutes and surgery continued. An FiO₂ of 0.3 in nitrous oxide was reintroduced ten minutes later without decrease in oxygen saturation. A similar episode occurred one hour later with a decrease in PETCO₂ from 33 mmHg to 21 mmHg over 30 sec but again no source of air entrainment was found. There was no change in arterial pressure, heart rate or oxygen saturation. A third decrease in PETCO₂ from 34.5 mmHg to 15 mmHg (Figure 1) developed half an hour

Key words

ANAESTHESIA: neurosurgical;
ANAESTHETIC TECHNIQUE, GENERAL: position, sitting;
EMBOLISM: air;
LUNG: oedema.

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FIGURE 1 End tidal carbon dioxide tracing showing sudden decrease from 34.5 to 15 mmHg.

later and on this occasion, was followed by a decrease in systolic arterial pressure from 150 to 110 mmHg. An infusion of Haemaccel 1000 ml and Ringer's lactate solution (RL) 500 ml was required to maintain haemodynamic stability. An FiO_2 of 1.0 was necessary to maintain the SaO_2 greater than 95%. The operation finished one and a half hours later with a total anaesthetic time of eight hours. The CVP had remained low (approximately 5 cm H_2O) despite a further 1000 ml fluid in the last hour. Auscultation of the chest revealed diffuse crepitations and there was pink frothy sputum in the endotracheal tube. The total fluid input was SPPS 1500 ml, NS 1500 ml, RL 1000 ml and Haemaccel 1000 ml with a urine output of 1250 ml and blood loss of approximately 500 ml. The patient was transferred to the intensive care unit (ICU) for further management.

In the ICU, his SaO_2 decreased to 90% despite a FiO_2 of 1.0 and a positive end expiratory pressure (PEEP) of 14 cm H_2O . He became hypotensive, tachycardic ($150 \cdot \text{min}^{-1}$) and oliguric with a CVP of 15 cm H_2O . This was accompanied by pyrexia (core temperature 40°C), leukocytosis ($40 \times 10^9 \cdot \text{L}^{-1}$) and a severe metabolic acidosis (pH 7.14) with a base excess of -13 . The electrolyte values were normal and the blood glucose was $11 \text{ mmol} \cdot \text{L}^{-1}$. The CXR showed diffuse opacities throughout both lung fields compatible with pulmonary oedema, chest infection or aspiration pneumonia (Figure 2). Broad spectrum antibiotics were started after appropriate specimens were taken for culture. Inotropic support was started with adrenaline and dopamine but the patient's condition continued to deteriorate with a systolic arterial pressure of only 70 mmHg.

A thermodilution pulmonary artery catheter was inserted. The pulmonary capillary wedge pressure (PCWP) was 13 mmHg with a cardiac output (C.O.) of $1.4 \text{ L} \cdot \text{min}^{-1}$, systemic vascular resistance (SVR) of $3086 \text{ dyne} \cdot \text{s} \cdot \text{cm}^{-5}$ (normal range: $770\text{--}1500 \text{ dyne} \cdot \text{s} \cdot \text{cm}^{-5}$) and pulmonary vascular resistance (PVR) of 1371

FIGURE 2 CXR showing bilateral diffuse mottling.

$\text{dyne} \cdot \text{s} \cdot \text{cm}^{-5}$ (normal range: $20\text{--}120 \text{ dyne} \cdot \text{s} \cdot \text{cm}^{-5}$). At this time, the haemoglobin concentration was $20.5 \text{ g} \cdot \text{dl}^{-1}$ with a haematocrit of 0.66. The patient had intense vasoconstriction and a low cardiac output, presumably secondary to massive fluid loss from pulmonary capillary leakage. An infusion of SPPS 1000 ml over 30 minutes increased the C.O. to $4.5 \text{ L} \cdot \text{min}^{-1}$. Amrinone was started because of its inotropic and vasodilating properties. A loading dose of 100 mg was followed by an infusion of $5 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The adrenaline was discontinued gradually. The protein content of the tracheal aspirate was found to be $56 \text{ g} \cdot \text{L}^{-1}$ while the plasma protein concentration was $70 \text{ g} \cdot \text{L}^{-1}$. Twenty-four hours later, with the continued infusion of amrinone and a total of SPPS 5000 ml, there was good peripheral perfusion with the following measurements: C.O. $5.0 \text{ L} \cdot \text{min}^{-1}$, arterial pressure 150/70 mmHg, heart rate $110 \cdot \text{min}^{-1}$, SVR $935 \text{ dyne} \cdot \text{s} \cdot \text{cm}^{-5}$; pH 7.35, base excess -3 ; core temperature 38.5°C and urine output $150 \text{ ml} \cdot \text{h}^{-1}$. A SaO_2 of 91% was maintained with a FiO_2 of 0.7 and PEEP of 10 cm H_2O . Amrinone was stopped on the second day and the trachea was extubated on the sixth day. His recovery was complicated by thrombosis of the

right subclavian vein which resolved with a short-term heparin infusion. Two episodes of melaena resolved with medical therapy. He was discharged to the neurosurgical ward with grade III left hemiparesis on day 14 and home on day 81. He is now fully independent with normal cerebral function.

Discussion

This patient presented some problems with diagnosis and treatment initially. The differential diagnosis of the pulmonary changes observed in our patient included infection, aspiration and oedema with a cardiogenic or non-cardiogenic cause. The initial leukocytosis and fever could have been misleading but infection was unlikely in view of the rapid development, diffuse involvement and rapid resolution of the pulmonary changes. There was no evidence of aspiration during induction or maintenance of anaesthesia and the pulmonary signs were bilateral and uniform. There were no signs of heart failure and the serial cardiac enzymes and ECG were all normal. Neurogenic pulmonary oedema is a well recognized syndrome but it is commonly associated with increased intracranial pressure and traction or injury to the brain stem. None of these factors was present in our patient and the post-operative CT scan of the brain was normal so a neurogenic cause was thought to be unlikely. The positive fluid balance near the end of surgery was not evidence of pulmonary oedema as a result of fluid overload, because the fluid was given in response to a low CVP and hypotension at a time when gas exchange was impaired already. Despite 4500 ml of fluid perioperatively, our patient still had a fluid deficit because of the massive leakage of protein-rich exudate into the lung. The haemoconcentration with leukocytosis and polycythaemia implicated volume depletion as the cause of the low cardiac output state.

Venous air embolism is a common and well-recognized complication of neurosurgical procedures in the sitting position but the incidence of severe morbidity or mortality is only about 1%.² A site of air entrainment is found only in 35% of cases,² and is less common in operations on the cervical spine than in the posterior fossa. There were no other independent methods to diagnose VAE apart from the typical trace from the decrease in PETCO₂. No air was retrieved from the central line but with the modern early detection of VAE, recovery of air may be minimal despite aspirating large quantities of blood.³ No characteristic "mill-wheel" heart murmur was heard although this is a rare, late sign present when there is a large bolus of air in the right ventricle. A Doppler would have been a more sensitive detector for VAE but was unavailable unfortunately. The decrease in PETCO₂ was typical of VAE and there was no change in other car-

diovascular or respiratory variables which would suggest another cause.

Losasso *et al.*⁴ concluded that the use of 50% nitrous oxide had no effect on the incidence or the severity of VAE in 300 neurosurgical patients. The same group also found that when venous air was infused at different rates into dogs, the administration of nitrous oxide did not improve the sensitivity of the transoesophageal echocardiography or precordial Doppler but did improve the sensitivity of PETCO₂ and pulmonary artery pressure monitoring in the detection of VAE.⁵

Pulmonary oedema after VAE may occur with neurosurgery,⁶⁻¹¹ or in awake non-surgical patients,^{12,13} but late severe cardiovascular collapse as a result of volume depletion has not been reported previously.¹⁴ Surprisingly, current neurosurgical textbooks^{15,16} and the few case reports in the anaesthetic literature^{6,8-10} contain either little information or outdated theories about the pathogenesis of the pulmonary oedema. A recent review on venous air embolism is the most informative.¹⁴ Pulmonary oedema may occur rapidly, or several hours later, but usually only after multiple episodes of air trapping.¹⁷ The oedema fluid is rich in protein because of the increase in pulmonary capillary permeability.¹³ In our patient, the diagnosis of pulmonary oedema secondary to VAE was supported by the occurrence of multiple episodes of VAE, the development of pulmonary oedema near the conclusion of surgery and the high protein content of tracheal aspirates.

It was thought initially that pulmonary hypertension or local hypoxia caused the pulmonary oedema,⁶⁻⁹ but these hypotheses were not supported by animal studies.¹⁸ Recent studies favour direct toxicity of air bubbles on the pulmonary endothelial cells. In animal lungs, there was aggregation of neutrophils around the air bubbles in the small pulmonary arteries and arterioles. Many neutrophils were in close contact with the pulmonary arterial endothelial cells in which were found gaps of 0.1–3.0 µm. Beneath these gaps, the basal lamina was disrupted. Protein-rich lung lymph flow was increased after VAE, signifying an increase in microvascular permeability.¹⁹ Endothelial damage was caused by the production and release of toxic oxygen metabolites by leukocytes. When sheep were depleted of circulating leukocytes, there was a dramatic decrease in lymph fluid and protein flows during VAE.²⁰ Similar results were found when sheep had a normal number of leukocytes but were treated with the enzyme superoxide dismutase which is a scavenger of the toxic superoxide anion released by activated leukocytes.²¹

This patient was elderly, diabetic and had some abnormalities in his ECG. These factors may all compromise the adaptability of the cardiovascular system so that

the use of the sitting position should be considered carefully. If VAE occurs and there is evidence of continued impairment of gas exchange or pulmonary oedema, we would recommend that controlled ventilation be continued postoperatively. Analysis of the oedema fluid and PCWP monitoring will assist the diagnosis and treatment of pulmonary oedema. The amount of fluid and protein leak into the lung should not be underestimated.

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