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A Case Report of Paradoxical Air Embolism Caused by Intrapulmonary Shunting During Liver Transplantation

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Paradoxical air embolism (PAE) during orthotopic liver transplantation (OLT) is relatively common. However, small quantities of air have minimal clinical significance.[1,2] Hepatopulmonary syndrome (HPS), a recognized sequeala of chronic liver disease, is caused by intra-pulmonary arteriolar vasodilation and presents as hypoxemia. These collaterals provide a route for PAE in the absence of a pressure gradient from the right to left sided heart chambers. To our knowledge, this is the first report of a clinically significant PAE via intrapulmonary shunts during OLT.

CASE DESCRIPTION

A 66-year-old male patient (100 kg, American Society of Anesthesiologists [ASA] IV, Model of End-Stage Liver Disease score, 24; creatinine, 69 μmol/L; bilirubin, 76 μmol/L; international normalized ratio, 1.79; sodium, 129 mmol/L) underwent OLT for alcoholic cirrhosis and hepatocellular carcinoma. His chronic liver disease manifested as portal hypertension, ascites, and history of encephalopathy. His main comorbid condition was diffuse, moderate coronary artery disease. Electrocardiogram showed Q-waves in the inferior leads. Stress testing showed a reduction in systolic function. Coronary angiogram showed a 60% to 70% proximal and 80% to 90% distal circumflex stenosis, a 70% first diagonal stenosis, and a 30% to 40% right coronary stenosis, which was managed medically in accordance with consultant cardiology advice. He had no other cardiac or pulmonary diseases and had not been investigated with arterial blood gas or formal contrast echocardiography preoperatively based on normal pulse oximetry of 97% in room air in accordance with our institution's recommendations.

Anesthesia was induced with midazolam (2 mg), fentanyl (200 μg), and propofol (100 mg) and maintained with sevoflurane in 45% oxygen. Muscle relaxation was achieved using rocuronium. Ventilation was mechanically controlled to maintain an end-tidal carbon dioxide pressure of 35 mm Hg with positive end-expiratory pressure of 5 cmH_2O. Monitoring included standard American Society of Anesthesiologists monitoring plus additional monitoring, including invasive arterial pressure (right radial artery), central venous pressure (CVP), and pulmonary artery pressure via the right internal jugular vein and transesophageal echocardiography (TEE).

After induction of anesthesia, SaO_2 was 100% with 50% inspired oxygen, blood pressure was 90/40 mm Hg without inotropic or vasopressor support, CVP was 3, pulmonary artery pressure was 56/14 mm Hg. Consistent with our standard institutional practice, the procedure was performed using a caval interposition technique and veno-venous bypass was not used. The native liver hepatectomy was complicated by blood loss from extensive portal and retroperitoneal varices. During dissection of the native liver, the surgical team inadvertently created a small injury to the right hepatic vein. This venous defect was immediately identified and repaired with a suture. After 3 hours of native liver dissection and 15 minutes after the repair of the hepatic vein the patient had a sudden-onset ventricular tachycardia causing cardiac arrest with loss of an arterial line waveform and end-tidal CO_2, accompanied by an absent pulse. The hemodynamic changes at this time are illustrated in Figure 1. Advanced cardiac life

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A.B. wrote the first draft of the article. D.A-A. wrote the description of surgical techniques used during the procedure and provided editorial input. M.S. Coimbatore Srinivas and M.W. provided editorial input (participated in writing of all versions of article). C.S., M.W. selected and described TEE clips relevant to this case report. All authors have read and approved the final version of the article.

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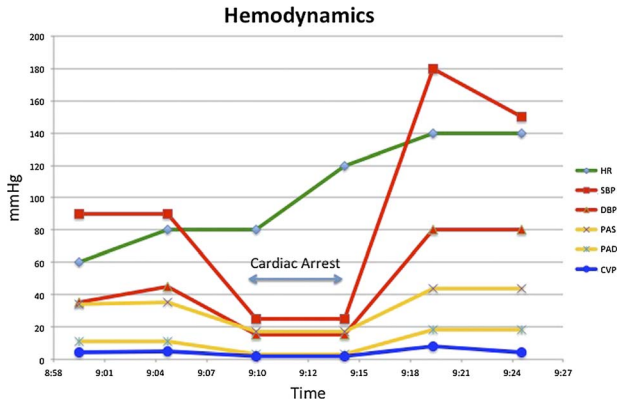

FIGURE 1. HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; PAS, pulmonary artery systolic pressure; PAD, pulmonary artery diastolic pressure.

support measures were instituted including cardiopulmonary resuscitation (CPR), defibrillation (1× 200 J biphasic) and boluses of Epinephrine (2000 μg total). After the first cycle of CPR, with the patient still hypotensive and in ventricular tachycardia, the TEE probe was turned on, revealing extensive air bubbles in both the right and left chambers of the heart (Figure 2 and **Video 1, SDC,** http://links.lww.com/PRSGO/A380). The origin of the left-sided air could be visualized entering the left atrium via the pulmonary veins. At this point, a diagnosis of PAE via intrapulmonary shunts was made but the source of entrainment was not clearly identified. The abdomen was filled with normal saline to prevent further air entrainment. This markedly reduced the intracardiac air, although small amounts of air continued to enter the left heart chambers, presumably due to recirculation. During the second cycle of CPR, there was return of spontaneous circulation, and CPR was stopped. The surgical team explored for sources of air entrainment but could not identify a specific source. Specifically, examination of the hepatic vein injury site revealed an intact repair. Dissection of the native liver was resumed and small quantities of new air were seen on the TEE but the patient remained stable with normal sinus rhythm and adequate blood pressure. No new air embolism was seen after the inferior vena cava (IVC) clamps were applied; confirming the source of air entrainment was distal to the suprahepatic IVC (Figure 3 and **Video 2, SDC,** http://links.lww.com/PRSGO/A381). The patient was cooled to 34°C for neurological protection and the remainder of the surgery was uneventful apart from significant blood loss (13 500 mL), requiring a massive transfusion. After the procedure, the patient was taken to the intensive care unit on inotropic and vasopressor support.

The patient's postoperative course was complicated by multiorgan dysfunction (acute respiratory distress syndrome, vasodilatory shock and acute renal failure). Normothermia was resumed on the first postoperative day after a seizure prompted a CT scan, which revealed a small subdural hematoma. The patient improved slowly over the following weeks but seizures, right-sided neglect and right arm weakness persisted. An MRI showed postictal changes and a small ischemic stroke in the territory of the right middle cerebral artery, consistent with cerebral air embolism.

DISCUSSION

This case report highlights the high index of suspicion required to diagnose intrapulmonary shunting as a cause of clinically significant PAE in patients with end-stage liver disease, including those not previously diagnosed with HPS. It also illustrates an advantage of intraoperative TEE monitoring in these patients, not previously reported in this context.

In this case, the combination of a potential source of air entrainment, a low CVP, and the presence of intrapulmonary shunts resulted in clinically significant PAE, leading to ventricular arrhythmia and cardiac arrest. This was most likely

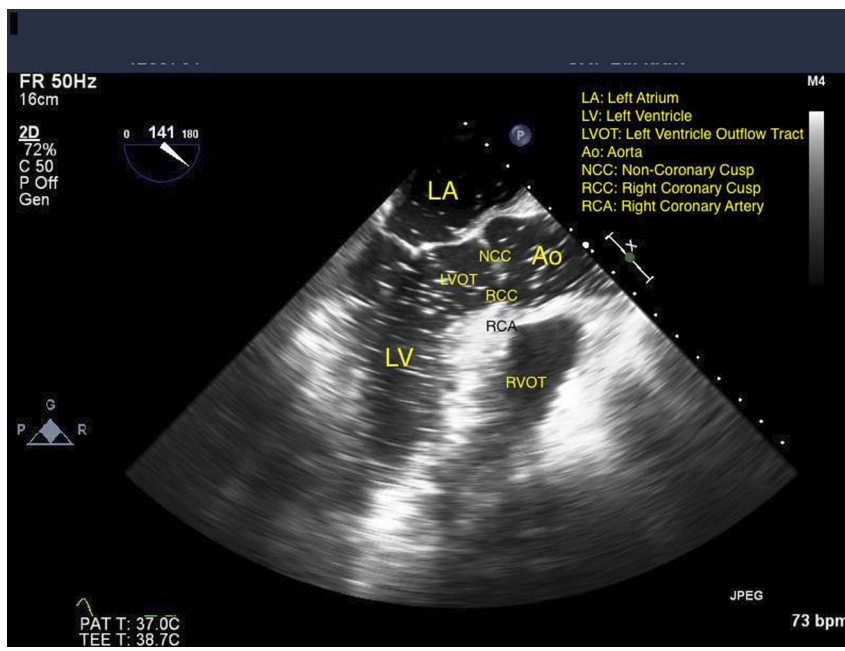

FIGURE 2. Air in the left ventricle and aorta.

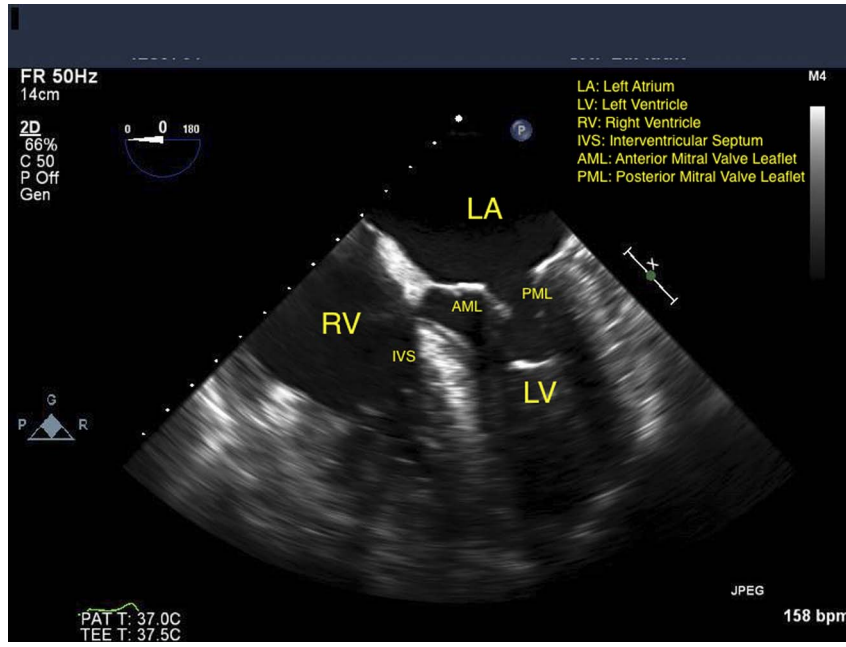

FIGURE 3. Post-IVC clamp.

caused by air entering the right coronary artery, resulting in temporary myocardial ischemia and associated arrhythmia. The exact source of entrainment could not be identified but appears to have been an intrahepatic or extrahepatic vessel distal to the suprahepatic IVC clamp.

Delayed diagnosis of PAE as the cause of cardiac arrest is likely to lead to worse cardiac and neurological outcomes and may be reduced by the use of TEE. However the use of TEE during OLT is a matter of debate and practice varies.[3,4] For noncardiac surgery, the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists (SCA) guidelines recommend TEE be used where the surgery or patient's cardiovascular pathology might result in severe hemodynamic, pulmonary or neurological compromise.[4] They also recommend that if equipment and expertise are available TEE should be used when unexplained life threatening circulatory instability persists despite corrective therapy.[4] The use of TEE during OLT may be associated with additional risks compared with other noncardiac surgeries, particularly variceal bleeding, previously considered both a relative and absolute contraindication depending on the center and operator.[5] However, retrospective studies show this risk is small.[6] The ASA/SCA guidelines recommend that TEE may be used in the presence of gastroesophageal varices if the expected benefits outweigh the potential risks.[4] In the event TEE is used in the presence of esophageal varices, it is recommended that precautions be taken such as using a smaller probe, minimizing probe manipulation and using the most experienced operator available.[4]

The benefits of TEE during OLT result from the provision of information not available via alternative monitors, including earlier detection of hypovolemia compared with CVP monitoring and detection/exclusion of valvular abnormalities, intra-cardiac shunts and thromboembolic events.[7-9] These findings often impact on patient management.[8] In this case, early placement (as opposed to rescue placement after the cardiac arrest occurred) allowed rapid diagnosis of PAE as a rare cause of cardiac arrest and contributed to improved cardiac and neurological outcome by expediting management.

In summary, this case highlights the potential for paradoxical embolism via intrapulmonary shunting in OLT recipients not previously diagnosed with HPS. It also highlights an advantage of TEE monitoring, specific to patients with end-stage liver disease, to rapidly diagnose PAE via intrapulmonary shunts, as an uncommon cause of hemodynamic instability.

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