

High values of intrathoracic blood volume in hepatopulmonary syndrome

Deepak Joshi, Elizabeth Sizer, William Bernal,
Julia Wendon and Georg Auzinger

Transpulmonary thermodilution (TPTD) monitoring of cardiac output and calculation of volumetric indices of preload are gaining popularity because of their relatively low invasiveness and greater accuracy for determining preload compared with measurement of central venous or pulmonary artery occlusion pressure.¹ Although target values for the intrathoracic blood volume index (ITBVI) and global end-diastolic volume index (GEDVI) have been established (and are published in the manufacturers' instruction manual), awareness is increasing of specific clinical scenarios where aiming for a "normal" ITBVI may be inappropriate. Extremely high ITBVI values have been reported in patients with abdominal aortic aneurysms and dilated cardiac chambers. We report two cases of persistently high ITBVI in patients with cirrhosis complicated by hepatopulmonary syndrome.

Clinical records

Patient 1

A 63-year-old man of European ancestry with end-stage liver disease secondary to alcohol use was admitted for orthotopic liver transplantation. Indications for transplantation were synthetic liver dysfunction (MELD [Model for End-Stage Liver Disease] score, 14; and Child–Pugh score, 7) and hepatopulmonary syndrome. The past medical history included emphysematous airways disease and an aortic abdominal aneurysm (4 × 5 cm). Before transplantation, the patient had hypoxaemia (Pao₂, 49.5 mmHg when breathing room air) and required high-flow oxygen for 20 hours per day. High-resolution computed tomography (CT) of the chest confirmed the presence of panacinar emphysema and prominent pulmonary vessels, but no evidence of collapse or atelectasis (Figure 1). No distinctive arteriovenous malformations were noted on CT.

The patient successfully underwent liver transplantation (piggyback implantation) with conventional biliary and vascular anastomosis. Postoperatively, he returned to the liver intensive therapy unit, intubated. He continued to require high levels of inspired oxygen (Fio₂, 0.70; and positive end-expiratory pressure, 10 cmH₂O) despite low target levels for Pao₂ (about 50 mmHg).

TPTD monitoring of cardiac output was undertaken with a PiCCO system (Pulsion Medical Systems, Munich, Ger-

ABSTRACT

Advanced haemodynamic monitoring via transpulmonary thermodilution (TPTD) devices has gained popularity in recent years. The intrathoracic blood volume index (ITBVI) and the global end-diastolic blood volume index (GEDVI) calculated by single indicator TPTD devices have been shown to reliably estimate cardiac preload. The normal range of values for ITBVI is provided by the manufacturers. Evidence is now emerging that certain clinical scenarios can lead to increased ITBVI values. We report two cases of persistently high ITBVI in patients with hepatic cirrhosis complicated by hepatopulmonary syndrome.

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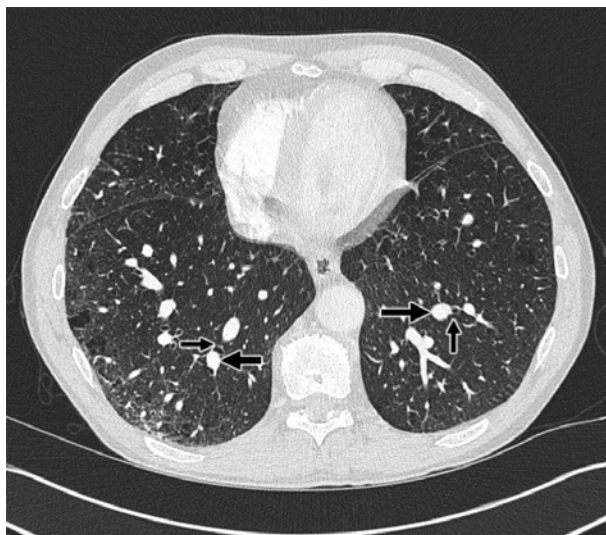
many), using a 5-Fr thermistor catheter placed in the left femoral artery, and injection into the superior vena cava. The ITBVI and extravascular lung water index (EVLWI) were significantly raised, at 1852 mL/m² (reference range [RR], 800–1200 mL/m²) and 15 mL/kg (RR, < 10 mL/kg), respectively, suggesting fluid overload. Negative fluid balances (mean, 1108 mL) failed to reduce the ITBVI (1765 mL/m²). There was no clinical evidence of fluid overload. A transthoracic echocardiogram showed normal-sized cardiac chambers, and normal valvular, systolic and diastolic function.

The patient underwent prolonged respiratory weaning, facilitated by a percutaneous tracheostomy, and remained in the liver ITU for 31 days. He did not require inotropic or vasopressor support, and was successfully discharged into ward care and eventually home, although dependent on home oxygen therapy (4–5 L via nasal specs).

Patient 2

A 42-year-old man, who was HIV-positive and had alcohol-related liver disease (MELD score, 13; and Child–Pugh Score, 7) and hepatopulmonary syndrome, successfully underwent orthotopic liver transplantation with the piggyback technique and standard biliary and vascular anastomosis. Preoperatively, the patient had a Pao₂ of 58.6 mmHg when breathing room air. Transthoracic echocardiography before and after surgery showed normal-sized cardiac

Figure 1. Computed tomography of the chest in Patient 1



Computed tomography showed panacinar emphysema and prominent pulmonary vessels — a large pulmonary artery (thick arrow) is contrasted with the associated bronchiole (thin arrow). There was no evidence of collapse, atelectasis or distinctive arteriovenous malformations.

chambers, and normal valvular, systolic and diastolic function.

Postoperatively, the ITBVI was high (1441 mL/m²). The patient remained in positive fluid balance (+2058 mL) and had polyuria. With subsequent negative fluid balances (mean, 1075 mL), the calculated ITBVI remained persistently elevated (mean ITBVI, 1476 mL/m² over 3 days). Clinical and radiographic findings were not consistent with intravascular volume overload. The patient did not receive inotropic and vasopressor support, and was successfully discharged from the liver ITU after 4 days. He was discharged home 20 days after surgery and did not require home oxygen.

Discussion

We describe two cases of persistently high ITBVI values without evidence of fluid overload in patients with proven hepatopulmonary syndrome. In both patients, TPTD monitoring was performed over a long period, and both the central venous injectate and arterial thermistor site were changed (not shown), with no significant effect on ITBVI values.

Hepatopulmonary syndrome is characterised by the triad of hepatic dysfunction, hypoxaemia and intrapulmonary vascular dilatation or distinct arteriovenous malformations.^{2,3} The alveolar–arterial oxygen difference (PAO₂ – PaO₂) is typically increased. Altered bowel perfusion and an

increased rate of enteral translocation of gram-negative bacteria and endotoxins are thought to increase secretion of nitric oxide, which in turn leads to pulmonary vasodilatation. The reported incidence ranges from 4% to 29% in patients with hepatic cirrhosis,^{4,5} but, as symptoms are non-specific (eg, fatigue and dyspnoea), this is thought to be an underestimate. Clinical signs include spider naevi, cyanosis, clubbing and telangiectasia. Orthodeoxia and platypnoea occur because of worsening diffusion–perfusion matching and an increase in shunt fraction in the upright position caused by increased perfusion of the lower lobes.

Hepatopulmonary syndrome is diagnosed by demonstrating hypoxaemia and evidence of pulmonary shunting. Chest CT findings include distal vascular dilatation associated with an abnormally large number of visible terminal vessel branches concentrated in the lower lung zones⁶ (Figure 1). An increased ratio of segmental arterial diameter to the adjacent bronchial diameter has also been described in patients with hepatopulmonary syndrome when compared with patients with normoxaemic cirrhosis.⁶

Advanced haemodynamic monitoring is essential to help assess cardiac function and guide optimal fluid and vasopressor therapy during liver transplantation. Single-indicator TPTD measurements of cardiac output, and volumetric markers of preload and extravascular lung water have become increasingly popular in intensive care. A cold saline bolus is injected into the central venous circulation, usually into the superior vena cava, and the change in blood temperature is detected by a thermistor-tipped catheter placed in the descending aorta. The TPTD technique enables quantification of the intrathoracic thermal volume (ITTV) based on the mean transit time (MTt_{cold}) (Box 1). The downslope time (DSt_{cold}) of the indicator multiplied by

Box 1. Principles of the transpulmonary thermodilutional technique

$$\text{ITTV} = \text{CO} \times \text{MTt}_{\text{cold}}$$

$$\text{PTV} = \text{CO} \times \text{DSt}_{\text{cold}}$$

$$\text{GEDV} = \text{ITTV} - \text{PTV}$$

$$\text{ITBVI} = 1.25 \times \text{GEDVI}$$

$$\text{EVLW} = \text{ITTV} - \text{ITBV}$$

Key

ITTV = intrathoracic thermal volume.

CO = cardiac output.

MTt_{cold} = mean transit time.

PTV = pulmonary thermal volume.

DSt_{cold} = downslope time.

GEDV = global end-diastolic volume.

ITBVI = intrathoracic blood volume index.

GEDVI = global end-diastolic volume index.

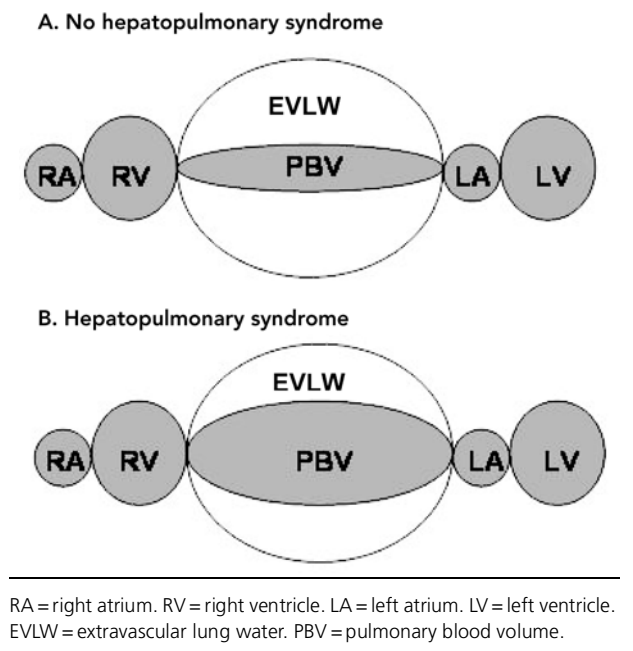
EVLW = extravascular lung water.

ITBV = intrathoracic blood volume.

Box 2. Potential causes of an increased intrathoracic blood volume index

- Abdominal aortic aneurysm
- Large cardiac chambers
- Hepatopulmonary syndrome

Figure 2. Fluid compartments in the absence and presence of hepatopulmonary syndrome



cardiac output allows measurement of the largest individual mixing chamber in differently sized chambers with similar flow. The pulmonary thermal volume (PTV) represents the largest mixing chambers. The global end-diastolic volume (GEDV) represents the end-diastolic volume of the right and left heart and is calculated by subtracting PTV from ITTV. A fixed relationship between ITBVI and GEDVI has been found ($ITBVI = 1.25 \times GEDVI$).

Although the manufacturers' instructions recommend injection of the cold bolus into the superior vena cava, Schmidt et al⁷ showed that injection via a femoral catheter can provide reliable cardiac output and EVLW index values, but overestimation of GEDVI needs to be taken into account. According to the manufacturers, the normal range for ITBVI is 800–1200 mL/m² and for EVLW is less than 10 mL/kg. These would be the accepted values for patients undergoing liver transplantation who do not have hepatopulmonary syndrome. However, ITBVI values can be increased in certain clinical scenarios (Box 2), because of prolongation of the

mean transit time at the injection or detector site, or an increased vascular reservoir. Patients with abdominal aortic aneurysms or large cardiac chambers can also have high ITBVI values because of larger mixing chambers.⁸ In these cases, Sakka and Meier-Hellmann⁸ recommended a Frank–Starling curve to assess individually the most appropriate value of ITBVI. In the setting of hepatopulmonary syndrome, the ITBVI may be increased because of a larger circulating pulmonary blood volume caused by dilatation of the pulmonary vessels (Figure 2).

Although our first patient had an aortic aneurysm, we believe that, given its small size, it could not have been responsible for the massive increase in ITBVI observed. It was effectively half the size of the aneurysm in the patient described by Sakka and Meier-Hellmann.⁸ Neither patient had enlarged cardiac chambers on echocardiography.

The diagnosis of hepatopulmonary syndrome is not common, but should be considered in all patients with chronic liver disease and hypoxaemia. ITBVI values may be consistently raised, and constitute a feasible marker to detect hepatopulmonary syndrome in intensive care patients.

Author details

Deepak Joshi, Registrar in Hepatology
 Elizabeth Sizer, Intensivist
 William Bernal, Intensivist
 Julia Wendon, Intensivist
 Georg Auzinger, Intensivist
 Liver Intensive Therapy Unit, Institute of Liver Studies, King's College Hospital, London, UK.
Correspondence: georg.auzinger@kch.nhs.uk

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