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EXPERIENCE IN THE USE OF INVASIVE HEMODYNAMIC MONITORING USING PREPULMONARY AND TRANSPULMONARY THERMODILUTION IN LUNG TRANSPLANTATION

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Objective: to demonstrate the experience of using complex hemodynamic monitoring by means of prepulmonary thermodilution (PPTD) and transpulmonary thermodilution (TPTD) – PiCCO – in lung transplantation (LTx). **Materials and methods.** Presented is a clinical case study of a 51-year-old patient with the following diagnosis: severe bronchiectasis and type 3 respiratory failure. Bilateral lung transplantation was performed at Sklifosovsky Research Institute for Emergency Medicine, Moscow. Intraoperative hemodynamic monitoring was performed using PPTD and TPTD techniques. **Conclusion.** The case study presented shows that simultaneous use of PPTD and TPTD for hemodynamic monitoring during lung transplantation achieves better treatment outcomes. This hemodynamics monitoring strategy is highly informative, allows for continuous measurement of necessary hemodynamic parameters and for timely and targeted correction of identified disorders by influencing the basic pathogenesis links of cardiovascular disease.

Keywords: lung transplantation, hemodynamic monitoring, transpulmonary thermodilution, PiCCO, prepulmonary thermodilution, intraoperative period.

BACKGROUND

Bilateral LTx is the only radical method for treating end-stage lung diseases [1, 2]. This type of surgical intervention often comes with hemodynamic instability at different stages, including during anesthesia induction, pulmonary artery clamping, after reperfusion and during implanted graft ventilation. Therefore, comprehensive continuous hemodynamic monitoring is necessary. Control of systemic and pulmonary hemodynamics is crucial for intraoperative management of this condition [1, 3, 4]. Adequate invasive hemodynamic monitoring allows for targeted correction of arising disorders by changing the infusion therapy tactics, using inotropic and vasopressor drugs, etc. [5].

Currently, there are no clinical guidelines for intraoperative hemodynamic monitoring in lung transplantation [1]. The main methods in this role are: invasive monitoring of blood pressure (BP), central venous pressure (CVP), PPTD using pulmonary artery catheterization (PAC), TPTD, transesophageal echocardiogram. TPTD allows a number of important hemodynamic parameters to be recorded: cardiac output (CO), CVP, pulmonary artery pressure (PAP), pulmonary artery occlusion pressure (PAOP), right atrial pressure, etc. [1, 6, 7].

The introduction of TPTD into clinical practice has made it possible to expand hemodynamic monitoring. The advantage of TPTD over PPTD is the measurement of a number of additional parameters, such as intrathoracic blood volume (ITBV), global end-diastolic volume (GEDV), extravascular lung water index (EVLWI), indicating the volumic status of the patient. TPTD method is less invasive and technically easier than PAC, the values obtained by TPTD more accurately reflect the formation of pulmonary edema, ahead of changes in gas exchange [8]. Volumetric monitoring by TPTD method is relevant in any critical conditions accompanied by impaired heart pumping function, increased permeability, gas exchange disorders, "capillary leakage" and tissue hypoperfusion, including patients undergoing LTx [3, 5].

Transpulmonary thermodilution method has been widely used in clinical practice with the advent of modern hemodynamic monitors PiCCO (Pulsion, Germany) [3, 6]. PiCCO monitoring technology combines two methods: transpulmonary hemodilution and arterial pulse wave analysis. It provides an assessment of volumetric preload, contractility, afterload indices, extravascular lung water volume, and cardiovascular response to volume load [5].

Simultaneous use of PPTD and TPTD makes it possible to obtain the results of measuring not only the pressures but also the volumes of all right and left heart chambers [6].

The **objective of this work** was to demonstrate the experience of comprehensive hemodynamic monitoring using PPTD and TPTD (PiCCO) in lung transplantation.

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CASE STUDY

Patient S., 51 years old, diagnosed with severe bronchiectasis. Bilateral LTx was performed at Sklifosovsky Research Institute for Emergency Medicine in Moscow.

Before induction of anesthesia, 100% oxygen was preoxygenated with an anesthesia mask. Fentanyl (3–5 μg/kg) and propofol (1.5–2 μg/kg) were used to induce anesthesia, and rocuronium bromide 1 mg/kg was applied for myorelaxation. After induction of anesthesia, a 39 Fr (Left Broncho-Cath; Mallinckrodt, Athlone, Ireland) double-lumen endobronchial tube was placed. Intraoperative artificial ventilation was performed using Drager Primus (Germany) in volume control mode (VCV) with 500–600 ml respiratory volume and 12–14 per minute respiratory rate with short inspiratory time and maximum expiratory time, maintaining peak inspiratory pressure <35 cm H_2O with oxygen fraction from 0.6 to 1.0. Positive end-expiratory pressure was 4 to 5 cm H_2O. Anesthesia was maintained with sevoflurane (0.5 MAC) and continuous infusion of fentanyl (2–4 μg/kg/hr). A warming blanket (Gamar Meditherm, Orchard Park, NY) was used to control body temperature.

Intraoperative monitoring included electrocardiography, pulse oximetry, capnometry, noninvasive and invasive blood pressure (BP), PPTD and TPTD using Dräger Infinity Delta XL+ PiCCO Dräger attachment system, Germany. A Dräger cardiac monitor (Germany) was used. For invasive BP monitoring after induction of anesthesia, we placed a catheter in the left radial artery 20 G (B. braun Germany). We also performed left subclavian vein catheterization with a 12 Fr three-lumen high-flow central venous catheter (B. braun, Germany) and inserted an 8.5 Fr introducer (Baxter Edwards Laboratories) into the right internal jugular vein to insert a Swan–Ganz catheter (F131HF7; Edwards LifeSciences, USA). A 5 F arterial catheter (Pulsiocath PV2015L20; Pulsion Medical System) was inserted into the left common femoral artery. Pressures in different parts of the vascular bed and/or heart chambers were measured with the reference point being the midaxillary line level and the fourth intercostal space plane, with the patient in a strictly horizontal position using a monitor. We also assessed acid-base status and water-electrolyte balance, determined SvO_2 and lactate using a Radiometer ABL800 Flex gas analyzer (Denmark). The patient did not require extracorporeal membrane oxygenation (ECMO) in the intraoperative period.

The patient was given an intravenous infusion of Sterofundin solution to replenish the initial volume. In case of a <3 decrease in cardiac index (CI), 5 to 8 mcg/kg/min dobutamine was administered against the background of infusion therapy. In hypotension with BP <60 mm Hg, 0.02–5 μg/kg/min norepinephrine was administered. Fresh frozen plasma was administered if INR >2. Red blood cell mass was transfused to maintain hemoglobin levels >9 g/dL. Intraoperative blood loss was recorded by measuring the volume of collected blood in a cell saver.

Central hemodynamic parameters – PAP, PAOP, CI, EVLWI, global end-diastolic volume index (GEDVI), ITBV, stroke volume index (SVI), systemic vascular resistance index (SVRI), etc. – were recorded at the following stages: after anesthesia induction, after left pneumonectomy, after left lung reperfusion, after right lung pneumonectomy, after right lung reperfusion, and after chest closure. Hemodynamic monitoring results are presented in Table.

Data analysis showed that initially, the patient's mPAP and PAOP were elevated relative to baseline after induction of anesthesia. After left pneumonectomy, there was increased CVP, mPAP and PAOP. Meanwhile, EVLWI remained at the same level, ITBVI slightly decreased. At the stage of pneumonectomy, during pulmonary artery clamping, there was a 2.7 l/min/m^2 decrease in CI, which required inotropic support (5 μg/kg/min dobutamine); CI was 3.4 l/min/m^2. After left lung reperfusion, a 1000 dyn·s·cm decrease in SVRI against the background of reperfusion syndrome, 15 ml/m^2 increase in EVLWI and 1145 ml/m^2 increase in ITBVI were detected. The clinical decision at this stage was to administer norepinephrine 0.2 mcg/kg/min and restrict infusion therapy and conduct dehydration (furosemide). The data obtained at the stage of right lung pneumonectomy showed a decrease in ITBVI and EVLWI, and an increase in SVRI. Due to the increase in EVLWI and ITBVI during right lung reperfusion, a decision was made to limit infusion therapy and perform dehydration (furosemide). This tactic allowed to correct the abnormalities. The obtained data indicated that CI and CAPWA values were consistent when measured by two methods. The volume of intraoperative infusion-transfusion therapy was 6200 mL, blood loss 1200 mL, urine volume 1900 mL, and perspiration volume 400 mL. The total balance was +2700 mL.

DISCUSSION

Central hemodynamic monitoring is necessary in LTx due to high likelihood of hemodynamic instability episodes and the need for their prompt correction [3, 7, 8]. Until now, there is no consensus on a hemodynamic monitoring method. This has created uncertainty in the choice of a particular method in this type of surgical intervention. In our opinion, this is due to the presence of a wide range of invasive and noninvasive techniques implemented in various hemodynamic monitoring devices, and the uniqueness of LTx as a surgical intervention, which consists in successively changing stages, accompanied by hemodynamic instability. According to a multicenter cross-sectional study evaluating the frequency of hemodynamic monitoring methods in LTx in different centers, PPTD is used in 69% of cases, while

PPTD and TPTD are used together in 17.8% of cases. Transesophageal echocardiography is used in most cases (89.3%) [7].

According to the literature, methods currently used in LTx have not been validated and each of them has limitations and shortcomings. Transesophageal echocardiogram is a widely used hemodynamic monitoring method [3]. Despite rapid diagnosis of hemodynamic instability using this method, it should be noted that it is an intermittent method, highly operator-dependent, and peak pulmonary venous flow velocities can be overestimated [7]. Operator dependence and high cost limit the use of transesophageal echocardiography in clinical practice, although its use in LTx is recommended in most countries.

The PPTD method is based on the StewartSwan–GanzHamilton principle, which describes the dilution of the indicator and requires a Swan–Ganz catheter equipped with a thermistor [6]. The obtained indicators are of clinical significance in cases complicated for pathogenetic interpretation. PPTD monitoring does not always fully reflect the volemic and hemodynamic status of a patient. According to Rocca et al., PAOP is not a reliable indicator for cardiac preload measurement, which is crucial for volumetric therapy and administration of inotropes and vasopressors [3].

The most comprehensive measurement of intraoperative hemodynamic parameters in LTx is possible with TPTD. In recent years, due to acceptable accuracy, less invasiveness and possibility of volumetric monitoring, TPTD has practically replaced the prepulmonary technique. The study conducted by Rocca et al. showed that ITBV is a more reliable indicator of cardiac preload compared to PAOP in LTx [3]. Similar results have been arrived at by Brock H. [9]. A number of researchers have demonstrated that such indicators as GEDVI and EVLWI in LTx allow predicting the development of primary graft dysfunction (PGD) and adjusting the treatment tactics accordingly in time [8, 10, 11]. Hofer C.K. showed that there is a close correlation between the data obtained by TPTD measurement and transesophageal echocardiography [12].

It should be noted that the use of PPTD and TPTD in the intraoperative period of LTx in case of ECMO has been questioned by a number of researchers because of the release of the indicator into the extracorporeal circuit at high flow [13, 14]. The need for venoarterial (VA) ECMO and venovenous (VV) ECMO in this surgery is often due to the need for hemodynamic support, correction of pulmonary gas exchange, and restoration of systemic perfusion, which in turn provides reperfusion and protective ventilation of the graft, thereby reducing ischemia-reperfusion injury [2, 15, 16, 17]. A study by Herner et al. demonstrated that both GEDVI and EVLWI are overestimated during TPTD in patients undergoing VV ECMO, but hemodynamic parameters such as CO, SV, SVI, CI, etc were not affected [13].

This clinical case study has demonstrated that simultaneous use of PPTD and TPTD in the intraoperative period during LTx is the optimal way for hemodynamic monitoring because of the wider range of parameters obtained.

Table

Results of PPTD and PiCCO monitoring at different stages of surgery

Indicators	After anesthesia induction	After left pneumonectomy	After left lung reperfusion	After right lung pneumonectomy	After right lung reperfusion	After chest suturing
BP avr., mm Hg	72	75	65	75	68	79
CVP, mm Hg	12	16	11	13	10	10
HR, bpm	88	98	100	107	110	99
PAOP, mm Hg (N = 6–12)	19	22	20	22	15	14
mPAP, mm Hg (N = 17–23)	51	59	35	43	26	25
CI, L/min/m^2 (N = 3–5)	3.4	3.3	3.4	3	3.4	3.4
ITBVI, mL/m^2 (N = 850–1000)	928	860	1145	956	1532	1100
SVV, % (N = to 10%)	12	10	8	7	5	7
SVRI, dyn·s·cm^{-5} (N = 1200–2200)	1411	1522	1270	1653	1325	1623
CCI_{art}, L/min/m^2 (N = 3–5)	3.4	3.4	3.3	3	3.5	3.4
SV, mL (N = 50–120)	65	53	56	50	59	57
EVLWI, mL/m^2 (N = 3–7)	7	8	15	12	20	9

Note: BP, blood pressure; CVP, central venous pressure; HR, heart rate; PAOP, pulmonary artery occlusion pressure; mPAP, mean pulmonary artery pressure; ITBV, intrathoracic blood volume; ITBVI, intrathoracic blood volume index; SVV, stroke volume variation; SVRI, systemic vascular resistance index; CCI_{art}, continuous cardiac index by arterial waveform analysis (PiCCO); CI, cardiac index (prepulmonary thermodilution using Swan–Ganz catheter); SV, stroke volume; EVLWI, extravascular lung water index.

CONCLUSION

The presented case study shows that simultaneous use of PPTD and TPTD for hemodynamic monitoring during lung transplantation achieves better treatment outcomes. This hemodynamics monitoring strategy is highly informative, allows for continuous measurement of necessary hemodynamic parameters and for timely and targeted correction of identified disorders by influencing the basic pathogenesis links of cardiovascular disease.

The authors declare no conflict of interest.

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