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Anesthetic management in lung transplantation: Our single-center experience

Akciğer naklinde anestezi yönetimi: Tek merkez deneyimimiz

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ABSTRACT

Background: In this study, we aimed to discuss our anesthesia management strategies, experiences, and outcomes in patients undergoing lung transplantation.

Methods: Between December 2016 and December 2018, a total of 53 patients (43 males, 10 females; mean age: 46.1±13 years; range, 14 to 64 years) undergoing lung transplantation in our center were included. The anesthesia technique, patients' characteristics, and perioperative clinical and follow-up data were recorded. The stage of lung disease was assessed using the New York Heart Association functional classification.

Results: Two patients underwent single lung transplantation, while 51 patients underwent double lung transplantation. Idiopathic pulmonary fibrosis was the most common indication in 41.5% of the patients. All patients had end-stage lung disease (Class IV) and 79% were oxygen-dependent. The extracorporeal membrane oxygenation support was given to 32 patients.

Conclusion: The anesthetic management of lung transplantation is challenging, either due to the deterioration of the recipient's physical performance and the complexity of the surgical techniques used. In general, a kind of mechanical support may be needed and extracorporeal membrane oxygenation is the first choice in the majority of patients. A close communication should be maintained between the surgeons, perfusion technicians, and anesthesiologists to ensure an optimal multidisciplinary approach and to achieve successful outcomes.

Keywords: Anesthetic management, lung transplantation, thoracic surgery.

ÖZ

Amaç: Bu çalışmada, akciğer nakli yapılan hastalarda anestezi yönetim stratejilerimiz, deneyimlerimiz ve sonuçlarımız tartışıldı.

Çalışma planı: Aralık 2016 - Aralık 2018 tarihleri arasında, merkezimizde akciğer nakli yapılan toplam 53 hasta (43 erkek, 10 kadın; ort. yaş: 46.1±13 yıl; dağılım, 14-64 yıl) çalışmaya alındı. Kullanılan anestezi tekniği, hastaların özellikleri ve perioperatif klinik ve takip verileri kaydedildi. Akciğer hastalığının evresi, New York Kalp Derneği fonksiyonel sınıflamasına göre değerlendirildi.

Bulgular: İki hastaya tek taraflı akciğer nakli ve 51 hastaya çift taraflı akciğer nakli yapıldı. İdiyopatik pulmoner fibroz, hastaların %41.5'inde en sık endikasyon idi. Hastaların tümünde son dönem akciğer hastalığı (Sınıf IV) mevcut idi ve %79'u oksijene bağımlı idi. Otuz iki hastaya ekstrakorporeal membran oksijenasyon desteği verildi.

Sonuç: Akciğer naklinde anestezi yöntemi, gerek alıcının fiziksel performansının kötüleşmesi, gerekse kullanılan cerrahi tekniklerin karmaşık yapısı nedeniyle zordur. Genel olarak, bir çeşit mekanik destek gerekebilir ve hastaların birçoğunda ekstrakorporeal membran oksijenasyonu ilk tercihtir. İdeal bir multidisipliner yaklaşım sağlamak ve başarılı sonuçlar elde etmek için cerrahlar, perfüzyonistler ve anesteziyolojistlerin arasında iyi bir iletişim kurulmalıdır.

Anahtar sözcükler: Anestezi yönetimi, akciğer nakli, göğüs cerrahisi.

Lung transplantation (LTx) is an effective therapy in end-stage lung diseases.[1] The main indications for LTx are end-stage suppurative, obstructive, restrictive, and vascular lung diseases.[2]

The first successful human LTx procedure was performed by Hardy et al.[3] at the University of Mississippi, United States in 1963 using an allograft from a cardiac-arrested donor. The advances in anesthetic drugs and techniques, the introduction of new technological and mechanical supportive devices, and the improvements in immunosuppressive medications and multidisciplinary approaches have led to an increase in the survival of patients undergoing LTx.[4,5]

In LTx operations, various complications may occur due to diversity in the underlying pathological conditions and those attributable to anesthesiological and surgical difficulties.[2] The strategies in LTx are mainly determined by the underlying pulmonary pathologies,[2] although there is a lack of data in the literature regarding perioperative anesthesia management in LTx.[6]

In the present study, we aimed to discuss our anesthesia management strategies, experience, and outcomes in patients undergoing LTx.

PATIENTS AND METHODS

This retrospective study was conducted at Kartal Koşuyolu High Specialization Education and Research Hospital, Department of Anesthesiology and Reanimation between December 2016 and December 2018. A total of 53 patients (43 males, 10 females; mean age: 46.1±13 years; range, 14 to 64 years) undergoing LTx were included. A written informed consent was obtained from each patient. The study protocol was approved by the Kartal Koşuyolu High Specialization Education and Research Hospital Ethics Committee (No: 2019.7723-239). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Preoperative preparation

In our institution, the indications for LTx were as follows: age <65 years, having a life expectancy of less than two years, unless LTx was performed, having sufficient nutritional status, care, and rehabilitation potential; and having no significant systemic disease or organ dysfunction. Donor selection criteria were as follows: age <55 years, blood group compatibility, intubation period of less than five days, not being a heavy smoker (20 pack-years), lack of Gram-negative or fungal growth in cultures, a partial oxygen pressure

(PaO$_2$)/fraction of inspired oxygen (FiO$_2$) P/F ratio of ≥250, positive end-expiratory pressure (PEEP) of 5 cmH$_2$O, lack of extensive infiltration, pneumothorax or trauma findings (contusion) on chest X-ray, and lack of a history of chronic lung disease.

In the preoperative period of anesthesia, significant organ dysfunction was ruled out based on the patients' examination and findings of a ventilation/perfusion (V/Q) scintigraphy, blood tests, pulmonary function tests, blood gas analysis in room air, electrocardiography (ECG), transesophageal echocardiography (TEE), coronary angiography, abdominal ultrasonography (USG), thoracic computed tomography (CT), upper/lower extremity venous Doppler USG, carotid and vertebral artery Doppler USG, 6-Minute Walking Test (6MWT), bone mineral density measurement, and cardiac catheterization.

Before surgery, five units of fresh frozen plasma (FFP), irradiated erythrocyte suspension (ES), and platelet suspension (PS) were made available. Immunosuppressive and prophylactic antibiotic regimens were arranged after consulting with chest diseases and infectious disease specialists. The patients were maintained on preoperative therapies (i.e., bronchodilator, antibiotics, and pulmonary vasodilator). The patients were administered intravenous famotidine 20 mg for antacid prophylaxis, and oxygen therapy was continued on-demand, until the patient was transferred to the operating room, if necessary. The patients did not receive any anesthetic agent for premedication purposes.

Intraoperative management

Anesthesia management

A five-lead ECG device, pulse oximeter, invasive blood pressure measurement from the left radial or brachial artery, urine bag for output monitorization and near-infrared spectroscopy (NIRS; INVOالسTM, Somanetics/Covidien, Irvine, CA, USA) for cerebral oxygenation monitorization were connected. Baseline values were recorded before anesthesia induction.

Underbody warming blankets were used in all patients. Body temperature was monitored using an esophageal temperature probe. In patients undergoing extracorporeal membrane oxygenation (ECMO), the body temperature was kept at 36.5°C by the ECMO warmer in the presence of hypothermia.

Anesthesia was induced through the administration of fentanyl 3 µg/kg, midazolam 0.08 mg/kg and propofol 0.5 to 1 µg/kg, and rocuronium bromide 0.08 mg/kg was used for muscle relaxation. Ketamine

1 to 2 mg/kg was administered to patients with limited cardiac reserve. Anesthesia was maintained with repeated doses of fentanyl 0.5 to 1 μg/kg, midazolam 0.05 mg/kg, rocuronium bromide 0.04 mg/kg, and with titration doses of sevoflurane 0.5 to 1.2%.

The endobronchial intubation tube was inserted into the side with high V/Q scintigraphy value. The anesthesia team used a pediatric fiberoptic bronchoscope (FOB) to check the position. In addition, 35, 37, and 39-Fr (Shiley™; Covidien, Irvine, CA, USA) endobronchial tubes were preferred based on the patient's sex, weight, and height.

The mechanical ventilation settings were as follows: FiO_2 100%, tidal volume (TV) 6 to 8 mL/kg, respiratory rate (f) 12 to 20 min, and PEEP 5 to 10 cmH_2O. The maximum peak inspiratory pressure was set at 40 cmH_2O, and the maximum plateau pressure was set at 35 cmH_2O. The inspiration/expiration ratio was adjusted, when hypercapnia was observed in the blood gas analysis or capnography data. After induction, the TEE probe was installed for cardiac monitorization by the anesthesia team. The patients routinely received 20 to 30 ppm inhaled nitric oxide (iNO).

After intubation, a central venous catheter (8.5-F; ARROW International Inc., PA, USA) was inserted into the right jugular vein and a pulmonary catheter (7.5-Fr 5 Lumen hands-off infusion port thermodilution catheter; ARROW International Inc., PA, USA). Central catheterization was performed using the Seldinger technique, and central venous pressure (CVP) was measured. Pulmonary artery catheterization (PAC), cardiac output (CO), mean pulmonary artery pressure (mPAP), pulmonary capillary wedge pressure (PCWP), and cardiac index (CI) were recorded using the thermodilution technique. During the operation, the pulmonary artery catheter was withdrawn, if it was on the side of the clamped pulmonary artery and directed to the other side. The CO measurements were made after the induction and at the end of surgery.

In all patients, extra-arterial and venous cannulation was performed from the femoral area for guiding purposes for possible ECMO after induction.

Single-lung ventilation (SLV) was performed to the native lung, while performing pneumonectomy. The mechanical ventilator was set to a TV of 4 to 6 mL/kg, FiO_2 of 100%, and a respiratory frequency of 14 to 15. The mechanical ventilator settings were re-adjusted by evaluating the etiology, follow-up blood gasses, pulse oximetry, and NIRS measurements to maintain optimal oxygenation and hemodynamic stability, with manual ventilation performed, if indicated.

As the vascular bed changed (single lung circulation) after pneumonectomy, the right and left heart functions were evaluated using TEE. Hemodynamic and complete blood count (CBC) parameters were re-arranged due to the loss of blood from the removed lung tissue.

After completing bronchial and vascular anastomoses, while the first side of the donor lung was preserved at a cold temperature, pulmonary artery circulation was started gradually for 15 min to warm the lung graft. Before ventilating the implanted lung, the bronchial anastomosis site was controlled by entering through the endobronchial tube with a pediatric FOB. While starting ventilation, atelectatic areas were inflated through manual ventilation slowly and in a controlled manner, in coordination with the surgical team.

Protective ventilation with a low TV (3 to 4 mL/kg), low FiO_2 (30 to 40%), and high respiratory frequency (14 to 15) was performed to preserve the implanted lung from barotrauma and reperfusion injury. Optimal oxygenation was maintained with frequent blood gas monitorization, and mechanical ventilation settings were re-adjusted to prevent hypercarbia and reperfusion injury.

Before beginning the exploration and pneumonectomy of the other native lung, an endobronchial tube was inserted to the side of the implanted lung. Perioperative TEE was performed by the anesthesia team to evaluate the right ventricular volume, tricuspid annular plane systolic excursion (TAPSE) value, and right and left heart function, and also to detect other possible cardiac pathologies.

In case of hemodynamic instability, the patients were administered norepinephrine (0.05 to 1 μg/kg/min), dobutamine (5 to 10 μg/kg/min), epinephrine (1 to 10 μg/kg/min), and ephedrine (5 to 10 mg, bolus) to maintain the mean arterial pressure (MAP) at ≥50 mmHg. Milrinone (0.3 to 0.7 μg/kg/min) was used in the patients with limited right ventricular function and high pulmonary pressure on TEE and PAC.

A cell-saver was inserted to all patients as a precaution against complications of massive intraoperative hemorrhage.

Crystalloid solutions were selected as the first-line fluid therapy, and the patients received fluid replacement therapy according to the optimal arterial

pressure and cardiac fullness on CVP and TEE. The cell-saver was used first, depending on hemodynamic changes due to intraoperative bleeding. Colloids and ES were administered, when hematocrit decreased below 28%, and hemoglobin dropped below 8 mg/dL. The FFP was used as a precaution against factor dilution, when three or more ES units were administered for massive hemorrhage. Similarly, PS was administered, when the platelet counts in the intraoperative CBC values were <80,000 μL in the patients with massive bleeding.

The intravenous fluids used to maintain a stable body temperature were warmed using a transfusion warmer.

The criteria for ECMO support were as follows: *(i)* patients with hemodynamic instability (MAP <50 mmHg) at any stage of the operation, despite inotropic agents, received veno-arterial (V-A) ECMO; *(ii)* during native lung ventilation with a FiO_2 of 100%, despite conventional mechanical ventilation strategies, patients with hypercarbia (partial pressure of carbon dioxide [$PaCO_2$] >60 mmHg), hypoxemia (PaO_2 <60 mmHg/oxygen saturation <80%), and a pH of ≤7.2 in a blood gas analysis received V-V ECMO, if hemodynamic status was stable; and *(iii)* when the implanted graft ventilation was started, V-V ECMO support was initiated, if the $PaCO_2$ was >60 mmHg, PaO_2 was <60 mmHg, oxygen saturation was <80%, FiO_2 was 60%, and pH was ≤7.2 in blood gas analysis.

At the end of the operation, the patients undergoing ECMO were evaluated for weaning. The ECMO was terminated, if the patient was hemodynamically stable and PaO_2 90-100 was mmHg, $PaCO_2$ was 35 to 45 mmHg, and mixed venous oxygen saturation (SvO_2) was 65 to 75% in the blood gas analysis. Patients without a TV of 8 to 10 mL/kg, having abnormal respiratory frequencies, those who were unable to breathe with PEEP within the acceptable limits (10 cmH_2O), and those with findings of low pulmonary reserves and right ventricular failure were transferred to the intensive care unit (ICU) under ECMO support.

At the end of the operation, the double-lumen endobronchial tube was swapped for an endotracheal tube, and blood gases and hemodynamic parameters were returned to optimal values. Also, bronchial anastomoses were checked using an FOB after the transplantation of the two lungs, which were, then, aspirated.

A bilateral blockade was performed by the surgical team through the third and fourth intercostal spaces at the site of the clam-shell incision using 0.5% bupivacaine 40 mg for analgesia. No thoracic epidural block was performed, due to the possible intraoperative heparin requirement.

In all patients, postoperative TEE and CO measurements were made by the anesthesia team.

Surgical procedure

All patients were placed in the supine position with both arms extended 90 degrees and with the scapulae supported by gel pads. A clam-shell incision was made to the fourth intercostal space, and the internal mammary artery was bilaterally ligated.

The recipient's pneumonectomy was planned to coincide with the timing of the delivery of the donor lung to the operating room. The organ harvested from the donor was stored in the Perfadex® solution (Xvivo Perfusion AB, Göteborg, Sweden) at +4°C. The lung with the lowest V/Q value was selected to operate on first. A clam-shell incision was made, the pericardium was opened, and the aorta and right atrium were prepared for a possible central (veno-atrial) V-A ECMO support by placing cannulation stitches. After the lung was released and the vascular structures and the main bronchus were explored, native SLV was started. The recipient pneumonectomy was completed. Before cutting the pulmonary artery with a stapler, 5,000 units of heparin were administered, and anticoagulation status was followed. An activated clotting time (ACT) of 160 to 200 was targeted, if the ECMO was to be used.

Bleeding control was made following the pneumonectomy. Grated sodium chloride (NaCl) ice was placed to cool the thoracic cavity. Firstly, bronchial and, then, vascular anastomoses were completed.

To prevent reperfusion injury, 500 mg of methylprednisolone was administered via infusion during anastomosis of the two pulmonary arteries, making a total dose of 1 g. The pulmonary artery clamp was released for 15 min, and the graft was allowed to warm.

After hemodynamic stability was achieved and the graft was warmed up, the SLV performance of the implanted lung was evaluated based on the blood gas analysis. Central V-A ECMO support was given in severe hypoxia, hypercarbia, hypotension, ECG changes, and pulmonary edema unresponsive to medical therapy.

Postoperative period

The patients were connected to the monitor, after transfer to the ICU and ventilated with

pressure-controlled mechanical ventilation (FiO_2 <60%, f: 10-14, TV: 6-8 mL/kg, PEEP <10 cmH_2O).

In patients receiving ECMO support, mechanical ventilator support (FiO_2 <40%, TV: 4-6 mL/kg, PEEP <5 cmH_2O, f: 8-10) was reduced in compliance with lung-preserving strategies.

Bronchial aspiration was repeated using FOB.

All patients were sedated in the postoperative first 24 h and remained connected to the mechanical ventilator. Propofol 1 to 2 mg/kg was used to achieve sedation. Extubation was planned on postoperative Day 1 in the patients with optimal hemodynamic and respiratory parameters.

Table 1. Preoperative patient characteristics (n=53)

	n	%	Mean±SD	Range
Age (year)			46.1±13	14-64
Sex				
Male	43	81		
Female	10	19		
Body mass index (kg/m²)			24.1±5	13-43
Etiology				
Idiopathic pulmonary fibrosis	22	41.5		
Bronchiectasis	12	22.6		
COPD	10	18.9		
Cystic fibrosis	4	7.5		
Adenocarcinoma	2	3.8		
Pleuroparenchymal fibroelastosis	1	1.9		
Sarcoidosis	1	1.9		
Silicosis	1	1.9		
Hemoglobin			12.9±1.8	9-18.3
Serum creatinine			0.7±0.2	0.4-1.39
Urea			33±15	
Lung function tests				
FEV1 (L)			1.2±0.6	0.44-3.92
FVC (L)			1.5±0.7	0.7-3.55
DLCO (mL/min/mmHg)			31±14.2	4-43
Arterial blood gas values (on room air)				
PO₂ (mmHg)			84±23.3	50-190
PCO₂ (mmHg)			53±16	16-67
pH			7.2±0.1	14-35
TAPSE			20±4.3	13-32
LVEF (%)			63.7±2.5	55-65
PAPs catheter (mmHg)			51±18.9	23-124
Cardiac index (L/min./m²)			2.7±0.7	1.48-4.7
Ischemic time (min)				
1st lung			330±84	220-460
2nd lung			380±95	310-690
NIRS (%)				
Left			70±9.4	50-88
Right			75 ±7.6	53-90

SD: Standard deviation; COPD: Chronic obstructive pulmonary disease; FEV1: Forced expiratory in one second; FVC: Forced vital capacity; DLCO: Diffusion capacity of lung for carbon monoxide; PO₂/PCO₂: Arterial oxygen and carbon dioxide partial pressure; pH: Power of hydrogen; TAPSE: Tricuspid Annular Plane Systolic Excursion; LVEF: Left ventricular ejection fraction; PAPs: Pulmonary Artery Systolic Pressure; NIRS: Near-infrared spectroscopy.

No thoracic epidural analgesia was preferred for the postoperative analgesia, as anticoagulation with heparin may be required in LTx operations. Postoperative analgesia was administered in the form of intravenous tramadol and paracetamol.

The patients receiving ECMO support in the postoperative period were evaluated individually for weaning. In the patients who were followed with V-A ECMO support, the support was gradually decreased to a level of 1.5 L/min and maintained at this level for 2 to 4 h, as early as possible in the postoperative period (preferably on Day 1), if the hemodynamic status was stable, if there was minimal or no inotropic support requirement, and if the need for respiratory support decreased. The ECMO support was stopped in hemodynamically stable patients who showed a significant improvement on chest X-ray. In the follow-up of patients undergoing V-V ECMO, the ECMO FiO$_2$ and sweep gas values were gradually reduced, as early as possible in the postoperative period (preferably on Day 1), if the need for mechanical ventilation was reduced, the respiratory parameters in the blood gas analysis were at an optimal level, and if there was a significant improvement on chest X-ray. The ECMO support was stopped, if a patient was able to breathe on a mechanical ventilator with a FiO$_2$ of <60% and within average pressure values, and remain stable for 2 to 4 h.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency.

RESULTS

Baseline demographic and clinical characteristics of the patients are presented in Table 1. Of all patients, 51 underwent double LTx. All patients had end-stage lung disease (Class IV) according to the New York Heart Association functional classification. The most common pulmonary pathology was idiopathic pulmonary fibrosis (IPF), followed by bronchiectasis and chronic obstructive pulmonary disease (COPD).

The intraoperative hemodynamic parameters and arterial blood gas analysis results of the patients are presented in Table 2. The mean pulmonary artery systolic pressure was 52.8±21 mmHg after the induction of anesthesia and 36.8±12.2 mmHg after the closure of the chest wall. The mean pH was 7.26±0.1 after the initiation of anesthesia and 7.33±0.1 after the closure of the chest wall.

Table 2. Intraoperative hemodynamic and arterial blood gas findings

	After induction	Following chest closure	
	Mean±SD	Mean±SD	Min-Max
Hemodynamic values			
HR (b/min)	92.8±11.4	94.9±14.5	65-120
Mean BP (mmHg)	85.7±8.5	87.2±6.4	68-96
CVP (mmHg)	11.5±2.7	10.4±1.9	6-20
PAP sys (mmHg)	52.8±21	36.8±12.2	17-124
PCWP (mmHg)	11.5±2.5	10.3±1.7	5-16
SpO$_2$ (%)	90.9±4.8	97.3±3.3	78-100
Arterial blood gas values			
pH	7.3±0.1	7.3±0.1	7.2-7.5
PO$_2$ (mmHg)	84.9±21.4	101.4±19.2	75-280
PCO$_2$ (mmHg)	55.8±13.6	44.1±6	20-100
Lactate (mmol/L)	1.3±0.9	3.5±2.3	0.7-9

SD: Standard deviation; Min: Minimum; Max: Maximum; HR: Heart Rate; BP: Mean Blood Pressure; CVP: Central Venous Pressure; PAP sys: Pulmonary artery pressure systolic value (pulmonary catheter); PCWP: Pulmonary Capillary Wedge Pressure; SpO$_2$: Arterial pulse oximetry; pH: Power of hydrogen; PO$_2$/PCO$_2$: Arterial Oxygen and Carbon Dioxide Partial Pressure.

Table 3. ECMO use

	Preoperative		Intraoperative		Postoperative	
ECMO	n	%	n	%	n	%
V-V	6	100	6	18.75	4	36.3
V-A	-	-	26	81.25	7	63.6

ECMO: Extracorporeal membrane oxygenation; V-V: Veno-venous; V-A: Veno-arterial.

Table 4. Mortality, Intubation duration and ICU stay

	n	%	Mean±SD	Min-Max
Early postoperative mortality (within 1 month)	10	18.86		
Postoperative mortality (within 1 year)	17	32		
Intubation duration (day)			3.5±2.7	1-10
ICU stay (day)			6.1±5.9	2-25

SD: Standard deviation; Min: Minimum; Max: Maximum; ICU; Intensive care unit.

The ECMO use rate is presented in Table 3. Accordingly, ECMO was used preoperatively in six patients and intraoperatively in 32 patients. Eleven patients undergoing ECMO in the postoperative period were transferred to the ICU under ECMO support.

Early mortality at one month was 10%, and the one-year mortality rate was 32% (Table 4).

DISCUSSION

Lung transplantation is the most effective treatment modality in patients with pulmonary pathologies. However, the anesthetic management of LTx is challenging due to the variety of underlying pathologies, the long waiting lists, and the deterioration of the recipients' physical performance.[2]

There are critical stages of anesthesia in LTx.[7] These include anesthesia induction, the start of positive-pressure ventilation, achieving SLV, clamping of the pulmonary artery, removal of the pulmonary artery clamp, reperfusion of the implanted lung, and bronchial and vascular anastomosis, particularly in the left lung.[7]

In our study, propofol, midazolam, fentanyl, and rocuronium bromide were preferred for the induction of LTx anesthesia. At the same time, propofol acts as an antioxidant due to the gamma and alpha-tocopherol contained within its formula.[8,9] The reason for choosing sevoflurane as the inhalation anesthetic is that it reduces inflammation and oxidative stress and preserves the lung against ischemia and reperfusion injury.[10,11]

The left side is often selected for endobronchial intubation in the LTx operations.[12,13] Different from the literature, a double-lumen tube was inserted into the lung side with a higher capacity according to the findings of the V/Q scintigraphy in our study. This approach aims at achieving a better gas exchange and a better tolerance of SLV. Furthermore, the tube interference to the anastomosis site was avoided, if surgery was started from the left side of the patient. The position of the endobronchial tube was checked by a pediatric FOB in all patients. When contralateral LTx was started, contralateral intubation was performed to keep the endobronchial tube away from the anastomosis site.

The frequency of hypoxia, hypercarbia, acidosis, cardiac arrhythmia, and cardiopulmonary arrest is high during induction. Cardiopulmonary bypass (CPB) and/or ECMO support may be required in case of emergency. Previous studies have suggested that femoral cannulation may be beneficial in high-risk patients during the induction of anesthesia.[7] We also performed femoral artery and vein catheterization for guiding purposes for possible V-A ECMO support after the induction.

The PAC is an important procedure for determining and treating CO, PAP, PVR, SvO_2, cardiac preload, right ventricular functions, and hemodynamic instability.[14] In the assessment of CO, an mPAP of >35 mmHg, CI of <2 L/min/m^2, and right atrial pressure of >12 mmHg are associated with high mortality.[15,16] In our study, for the patients meeting

the criteria for high mortality based on the PAC assessment after induction, anesthesia management was organized considering perioperative inotropic support and ECMO support.

Intraoperative TEE has the ability to identify right and left ventricular dysfunction and regional wall motion defects, investigate the causes of hemodynamic instability, evaluate volume status, and detect congenital anomalies such as patent foramen ovale and intracardiac pathologies, such as a thrombus, thereby, providing a road map for anesthesia management.[6] We consider that the joint assessment of TEE and PAC measurements after the induction of anesthesia would allow more effective and controlled anesthesia management during surgery. We also believe that it would allow the prediction of deterioration in the patient's condition, thereby, guiding the arrangement of medical and mechanical supportive therapies.

In the study of Tomasi et al.,[6] the NIRS, which is a helpful monitorization tool, was not used in 60% of LTx centers in the Europe and the United States, when PAC and TEE were jointly used in the assessment. The NIRS also provides necessary information about postoperative cognitive dysfunction in case of prolonged hypoxia.[17,18] In our study, we used NIRS monitorization in all patients during LTx. Significant decreases in the NIRS measurements were the indicators of hypoxia before pulse oximetry monitoring. We believe that this finding would allow the correction of intraoperative hypoxia, before it becomes more profound. Furthermore, when baseline NIRS decreased below 75%, oxygenation status, arterial tension, hemoglobin, PaO_2, and $PaCO_2$ values were evaluated and optimized in respective order.

The indication for LTx was restrictive disease and/or COPD in the majority of the patients undergoing transplantation since 2007.[7,19] The most common indications for LTx in our study were IPF, bronchiectasis, and COPD, respectively.

The ECMO or CPB may be preferred for mechanical support in patients that fail to respond to pharmacological therapy.[1,6] The preference for ECMO over CPB in our center is based on the fact that higher ACT values using higher heparin doses are required in CPB, and there is a greater need for blood and blood products. Also, the literature shows a higher rate of cytokine release/inflammatory system activation in patients undergoing CPB.[20,21] It is also reported in the literature that LTx operations under CPB are associated with higher tracheostomy rates, prolonged intubation, and prolonged stay in the ICU.[22,23] The rate of intraoperative ECMO use in our patients was 60.4%. Of these patients, 11.3% were followed with ECMO support in the preoperative period, while 20.7% were transferred to the ICU while receiving ECMO support after surgery. The rate of ECMO use in LTx operations was reported to be 27.4 to 45% in previous studies.[24-26] The high rate of ECMO use in our series can be attributed to the high number of marginal donors due to the low number of donors and the high number of high-risk patients on our waiting list.

The use of a retractor to expose the surgical site fully, particularly in left lung anastomosis, is one of the most common causes of hemodynamic impairment. Furthermore, atrial fibrillation with a rapid ventricular response is not rare. In our study, hemodynamic status was stabilized using V-A ECMO, when faced with clinical problems that could not be overcome by medical therapy.

There is a lack of consensus on fluid replacement therapy and/or blood/blood products in LTx operations.[27,28] Fluid replacement therapy in our study was optimized based on hemodynamic monitorization, blood gas analysis, and TEE. Arrhythmias such as tachycardia and atrial fibrillation were more common as a reflection of preoperative hypovolemia, and a consequence of surgical traction in the patients receiving fluid restriction intraoperatively, leading to the unnecessary use of inotropic agents and ECMO by impairing the hemodynamic status. Although we make great efforts to keep the patient dry, we must administer more fluids than required under certain conditions to ensure sufficient perfusion as the primary target in vital organs. On the other hand, there are studies suggesting that volume overload results in the development of postoperative primary graft dysfunction.[29] As a result, the amount and type of fluid resuscitation is essential, if the development of edema in the graft is to be avoided, while preserving hemodynamic stability and oxygen supply to the tissues. Crystalloid solutions were selected at the first line of treatment in our series. A lactated ringer solution was preferred. Although colloid solutions have been associated with postoperative poor lung functions,[2,28] colloid fluids and blood/blood products were used in this series, taking into account intraoperative hemoglobin levels, hemodynamic changes, and coagulation status.

The main limitation in LTx is the low number of available donors. This results in a need to use marginal donor organs, thus increasing postoperative mortality.[24] The rate of one-year mortality after LTx is reported to be 17 to 50%.[30,31] The one-year mortality rate in the present study was 17%.

The small sample size and relatively short duration of follow-up, compared to reputable LTx centers abroad, are the main limitations to the present study.

In conclusion, the anesthetic management of lung transplantation can be challenging, due either to the deterioration of the recipient's physical performance and the complexity of surgical techniques. In general, mechanical support may be needed, with extracorporeal membrane oxygenation being mostly the first choice. Also, a close communication should be maintained between the surgeons, perfusion technicians, and anesthesiologists to ensure an optimal multidisciplinary approach and, thus, to achieve successful outcomes.

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