Current Anesthesiology Reports (2019) 9:430–435
https://doi.org/10.1007/s40140-019-00362-9

The Role of Extracorporeal Life Support in Thoracic Surgery

Torsten Loop[1] · Johannes Kalbhenn · Axel Semmelmann[1]

Published online: 16 November 2019

Abstract

Purpose of Review Extracorporeal life support (ECLS) is a widely used potential treatment option in patients with severe respiratory or cardiac failure with increasing significance. Routine perioperative application of ECLS is applied in cardiac and rare in thoracic surgery. This review will address the extracorporeal membrane oxygenation (ECMO) technology and basic concepts, the indications in thoracic surgery, and the intraoperative management of ECMO during surgery. The most common challenges and complications, the postoperative concept, and additional forms of support will be discussed.

Recent Findings Technological advances in ECMO components may allow complex thoracic surgical procedures in patients in whom one-lung ventilation cannot be carried out safely without risk of hypoxia or right ventricular failure.

Summary The indications of ECLS in thoracic surgery besides lung transplantation are mainly airway resection and reconstructive surgery in patients with obstructive tracheobronchial airway diseases. Rare indications are lung surgery in patients with poor pulmonary reserve and difficulty or impossibility of one-lung ventilation. The intraoperative management of ECMO during thoracic surgery needs professional expertise.

Keywords Extracorporeal life support · Thoracic surgery · Extracorporeal membrane oxygenation · One-lung ventilation · Airway surgery

Introduction

The lung is the central organ and vital part for the respiratory gas exchange of oxygen and carbon dioxide. The alveolar surface is the membranous interface between pulmonary blood circulation and the ambient atmosphere.

Extracorporeal membrane oxygenation (ECMO) or extracorporeal life support (ECLS) is a widely used potential treatment option in patients with severe respiratory or cardiac failure with increasing significance [1•]. Routine perioperative application of ECLS is applied in cardiac surgery. However, ECMO treatment in general thoracic surgery is rare and is mainly applied during lung transplantation [2, 3, 4•]. ECMO may be considered an alternative to the use of jet- or cross-table ventilation in tracheobronchial surgery or with additional hemodynamic support (ECLS) during extensive oncologic resections in selected cases involving cardiovascular structures.

Technological advances in ECMO components resulting in reduced side effects such as bleeding may allow a safe surgical performance of complex thoracic surgical procedures or allow life-saving procedures in respiratory-compromised patients in whom one-lung ventilation cannot be carried out safely, without risk of hypoxia or right ventricular failure.

This review will address the ECMO technology and basic concepts, the indications in thoracic surgery, and the intraoperative management of ECMO during surgery. The most common challenges and complications, the postoperative concept, and additional forms of support will be discussed.

What Is ECLS? ECLS Technology, Components, and Basic Concepts

During the last 50 years, various extracorporeal systems were developed, characterized by specific modes of gas exchange, blood flow, and cannulation. The nomenclature of extracorporeal life support systems includes extracorporeal life support (ECLS), extracorporeal membrane oxygenation (ECMO), interventional

This article is part of the Topical Collection on *Thoracic Anesthesia*

✉ Torsten Loop
torsten.loop@uniklinik-freiburg.de

[1] Department of Anesthesiology and Critical Care Medical Center, Faculty of Medicine, University of Freiburg, Hugstetter Strasse 55, Freiburg im Breisgau, Germany

lung assist (iLA), extracorporeal carbon dioxide removal ($ECCO_2R$), or ventricular assist device (VAD) [5••].

ECMO, as a type of ECLS, is used to support or completely replace the physiologic function of pulmonary gas exchange by an artificial membrane ("lung") to deliver O_2 and remove CO_2. The key determinants of oxygen delivery during ECMO are the amount of blood flow through the circuit and the oxygenation capacity of the membrane. Physiologic oxygenation depends on the patient's native circulation (i.e., cardiac output) and the native lung oxygenation. Modern veno-venous ECMO circuits are able to completely process the cardiac output with a pump flow of 5–7 l/min, if an entire lung support is required.

A detailed description of ECLS technology and configuration has been previously described elsewhere [6, 5••]. In summary, ECLS systems usually combine a centrifugal pump generating a constant flow and a hollow fiber bundle membrane for oxygenation and carbon dioxide removal of venous blood drained through a large bore cannula located in a central vein. The return of the arterialized blood may either lead into the right atrium (veno-venous-ECMO (vvECMO)) or into a femoral or subclavian artery (veno-arterial ECMO) by percutaneous cannulation (see Fig. 1). Veno-venous techniques allow oxygenation and decarboxylation irrelative of pulmonary ventilation but require sufficient cardiac function and pulmonary perfusion. Veno-arterial ECMO can provide stable hemodynamic conditions, if right ventricular (RV) function becomes insufficient, for example, after clamping of pulmonary vessels. Depending on the cannula size and pump system even a full cardiopulmonary bypass can be established using vaECMO without cardioplegia [7, 8].

Percutaneous insertion of cannulas by the Seldinger technique can be performed pre-operatively in local anesthesia with sonographic guidance. This helps maintain respiratory and hemodynamic stability during induction of anesthesia. Intraoperatively, the returning cannula may also be inserted in the left atrium through a pulmonary vein or via the ascending aorta [9]. Both techniques allow the bypass of the lungs and make the effects of extracorporeal blood flow independent of pulmonary perfusion [10, 11]. When vaECMO is established via the femoral vessels, the direction of the artificially generated blood flow within the aorta reverses from caudal to cranial. Cerebral oxygenation may therefore be dependent on either the retrograde blood flow from the descending aorta or the residual ejected stroke volume of the heart. In the latter case, oxygenation of the head still depends on the pulmonary function [12]. To avoid and rapidly detect hypoxia of head and upper body ("Harlequin's phenomena"), we strongly recommend application of near-infrared spectroscopy (NIRS) for monitoring of cerebral oxygenation [13].

Surgery and ECLS

As ECLS and/or ECMO are increasingly used in patients with cardiac and/or pulmonary failure, the need for noncardiac surgical procedures in these patients will continue to increase and is mainly dominated by surgical procedures of complications and emergency operation. In a retrospective register study, nearly 50% of > 500 patients required surgery while on the ECMO period. General surgical procedures (39%) with

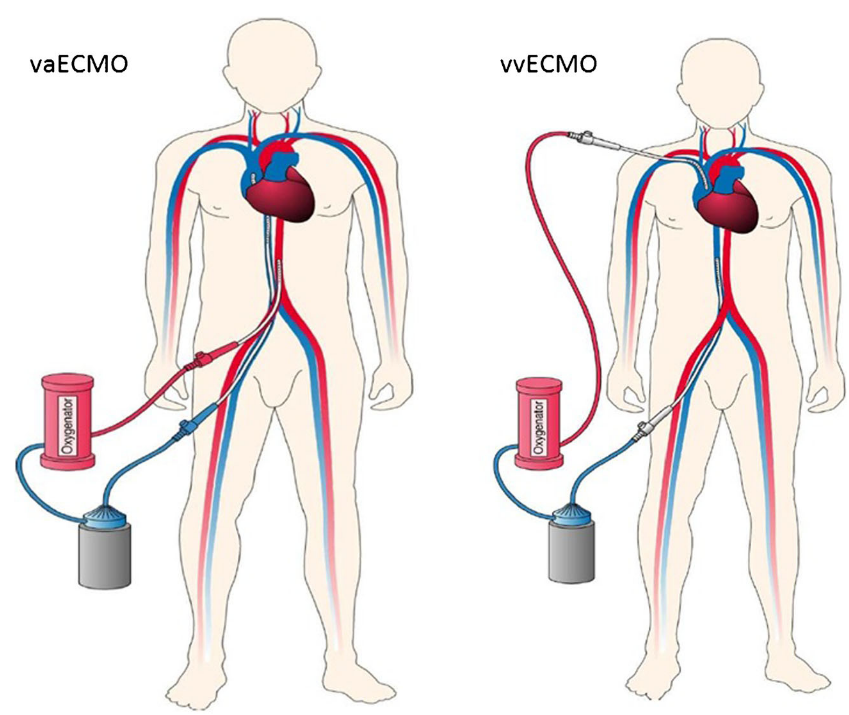

Fig. 1 The return of the arterialized blood may either lead into the right atrium (veno-venous-ECMO (vvECMO)) or into a femoral or subclavian artery (veno-arterial ECMO) by percutaneous cannulation

abdominal exploration/bowel resection (18%) being the most common. Vascular (30%) and thoracic procedures (23%) were also common, [14] although surgical procedures in patients supported with ECMO in this study did not increase mortality but resulted in increased morbidity and longer hospital stay. In addition, general surgery problems are common among patients on ECMO.

Indications of ECLS in Thoracic Surgery

Predominantly, ECMO in thoracic surgery is used in lung transplantation in patients with end-stage lung disease. Hemodynamic or ventilatory disturbances during lung transplantation can develop during induction of anesthesia or surgical dissection and difficult one-lung ventilation with the increased risk of hypoxemia, hypercapnia, and right heart ventricular failure during pulmonary artery (PA) clamping. Elective application of ECMO may offer hemodynamic stability and adequate gas exchange. Moreover, ECMO supports controlled reperfusion after PA de-clamping with reduced PA perfusion pressure on the allograft vasculature avoiding potential overperfusion. Failure of the left ventricle after a sudden drop in the pulmonary vascular resistance after implantation of the new lung in patients with previous pulmonary arterial hypertension can be prevented by continuing ECLS in the postoperative period to allow adaptation [15].

Intraoperative vaECMO is preferred over vvECMO to maintain adequate cardiac output in patients with right heart ventricular dysfunction [16, 17]. The use of ECMO during lung transplantation may be compromised by impaired volume status since—in contrast to cardiopulmonary bypass surgery—there is no venous reservoir in the ECMO circuit. Blood loss from the surgical field must be processed through a cell saver prior to reinfusion. Nevertheless, ECMO initiation and maintenance is relatively simple and offers significant advantages to complete cardiopulmonary bypass.

Further indications for ECMO may be supporting airway resection and reconstructive surgery in patients with obstructive tracheobronchial airway diseases [18•]. If cross-field ventilation and/or tubeless ventilation through a jet catheter as first choice are insufficient, ECMO support facilitates open-airway procedures in cardiorespiratory-impaired patients [19, 20]. Carina sleeve resections were also reported with the use of vvECMO [21–23].

Surgery in patients with poor pulmonary reserve who need lung resection and difficult or impossible one-lung ventilation (i.e., previous pneumonectomy patients scheduled for wedge resections) is rarely performed and remains a challenging task for thoracic surgeons and anesthesiologists. ECMO may allow a safe performance of this rare operation [2, 24]. Rinieri et al. demonstrated in a retrospective study the successful application of ECMO as respiratory support during the thoracic surgical procedures in 36 patients. Surgical indications were mainly neoplastic, infections, trauma, and iatrogenic complications. Twenty patients had surgery with vvECMO and 16 with vaECMO with 10 peripheral and 6 central cannulations. There was no intraoperative mortality; hospital mortality on day 30 was 17% (6 deaths). Presumably a multidisciplinary approach and decision-making process, the perioperative use of vv- or vaECMO in the above mentioned patients allowed to an extent the indication of thoracic surgical interventions with a calculated increased perioperative risk.

Anterior mediastinal mass syndrome can be life-threatening due to a sudden vascular, cardiac collapse or airway obstruction. General anesthesia augments such deleterious mass effects on the cardiopulmonary circulation. Therefore, perioperative management is to be designed to avoid factors resulting in collapse or include a strategy to bypass the potentially obstructed structures by the pathology. Femoral vaECMO with maintained spontaneous ventilation has been described and successfully prevented cardiovascular collapse in this indication [25].

There are no distinct criteria which patients will require perioperative extracorporeal support. Preoperative planning of ECLS requires a thorough evaluation of cardiopulmonary function and reserve. Furthermore, it should include imaging modalities such as ventilation/perfusion scintigraphy, echocardiography, and spiroergometry. In case of a promising surgical approach, therapy should not be withheld on the feasibility of ECLS.

Intraoperative Management of ECLS

The equipment and requirement used for ECLS support encompass nearly the same basic components used for cardiopulmonary bypass during cardiac surgery. Important differences in characteristics of ECLS are the smaller priming volume, the lack of a reservoir, lower heparin dose (50–100 U/kg), and a target activating clotting time of 150–180 s. In selected cases, heparin dose can even be minimized. When planning the preoperative ECLS strategy, the design should include the following factors:

- One or two cannulas
- Central or peripheral cannulation
- Patient's position during surgery
- Kind and extent of surgical procedure
- Patient's comorbidity
- Hemodynamic monitoring
- Medication (i.e., vasoactive drugs, inhaled NO)
- Postoperative ECLS weaning (i.e., on ICU or directly in OR)
- Anesthesia (i.e., non-intubated, airway management, epidural anesthesia)
- Expertise of medical staff

- Additional personal and structural framework requirement (i.e., cardiovascular perfusionist)

Further consideration and consequences in anesthesia management during ECMO may contribute due to altered drug effects induced by the change in pharmacokinetic distribution volume, adsorption, vasodilatation, and increased capillary permeability.

Several questions regarding mode and characteristics or settings of mechanical ventilation during ECMO are still unanswered:

- Which PEEP level and/or FiO_2 should be set?
- Which tidal volume is protective?
- Which gaseous and pump flow are optimal (< 60 ml/kg/min)?
- Which coagulation parameters and targets should be measured routinely before/during thoracic surgery and ECMO (ACT 150–180 s?; activity of factor anti-Xa? Thrombelastography?)

Challenges and Complications of ECLS

The major complications of ECLS are bleeding as cerebral hemorrhage or stroke or surgical site hemorrhage [26–28]. Further ECLS-associated side effects are patient related: injury during cannulation, organ ischemia (i.e., stroke and limb), renal failure, lung injury, infections, transfusion related complications, pain, delirium, and fear. ECLS-associated technical complications may be pump or membrane failure, air embolism, circuit clotting, hemolysis, and others.

The ECLS-induced coagulation disorders in a very short course [30]. Duration of extracorporeal support should be restricted and anticoagulation should be carefully indicated and monitored [29–31].

Recommendations and troubleshooting during intraoperative ECLS depend on the clinical situation:

- Hypoxia:

– Increase pump flow up to > 2/3 of cardiac output
– Set 100% O_2 on the oxygenator
– Check pO_2 on the oxygenator (> 150 mmHg)

- Hypercapnia:

– See settings hypoxia plus doubled gaseous flow to pump flow

- Re-Circulation (vvECMO):

– Check venous pO_2 (< 50 mmHg)
– Echocardiography
– Cannula repositioning

- Technical complications:

– Drop out of the complete or components of extracorporeal circuit
– Tube rupture or kinking
– Disconnection
– Thrombosis
– Air emboli
– Insufficient position or dimension of cannula

Postoperative Concept

Primarily, planned ECLS or ECMO support should not extend into the postoperative ICU therapy. Nevertheless, weaning from the extracorporeal support is less standardized and some recommendations are published online (www.elso.org). The weaning process from vaECMO and vvECMO may be different. The main postulation must be an optimal assessment of cardiac and pulmonary recovery before the decision to decannulate. For vvECMO, the procedure is more straightforward. Full lung function recovery corresponds with ventilator settings which allow protective ventilation. The pump flow could be stepwise reduced to 1.5 l/min while gaseous flow parallel is shut off. If oxygenation and ventilation remain stable, the system should be removed. Removal of vaECMO depends on involvement of cardiovascular structures in the surgical procedure and hemodynamic situation. Echocardiographic assessment facilitates the decision. The current status of anticoagulation of the patient should be tested before the ECMO system is removed in the OR and decannulation with manual compression is carried out [32].

Perspectives

The ECLS technology as a successful tool to manage oxygenation, hypercapnia, and hemodynamic support may lead to thoracic surgery to increased use in elective pulmonary procedures. Nevertheless, decision making is individual, depends on institutional expertise, and should be made conservative.

Conclusions

- The indications of ECLS in thoracic surgery besides lung transplantation are mainly airway resection and reconstructive surgery in patients with obstructive tracheobronchial airway diseases.

- Rare indications are lung surgery in patients with poor pulmonary reserve and difficulty or impossibility one-lung ventilation.
- The intraoperative management of ECMO during thoracic surgery needs professional expertise.
- The configurations and the application of ECLS are complex and may be associated with various complications (i.e., cannulation, technology, anticoagulation).
- The use of ECLS for thoracic surgery is a treatment for specialized centers.

Compliance with Ethical Standards

Conflict of Interest Torsten Loop, Johannes Kalbhenn, and Axel Semmelmann declare they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors..

References

Papers of particular interest, published recently, have been highlighted as: • Of importance •• Of major importance

1.• Karagiannidis C, Brodie D, Strassmann S, Stoelben E, Philipp A, Bein T, et al. Extracorporeal membrane oxygenation: evolving epidemiology and mortality. Intensive Care Med. 2016;42(5):889–96. https://doi.org/10.1007/s00134-016-4273-z. **This retrospective study demonstrated the recent increase in ECMO utilization, which is associated with a reduction in the in-hospital mortality. Importantly, the overall mortality in ECMO patients, particularly in patients with short-term ECMO use and older patients, still remains high, which is in contrast to findings of prospective studies performed by highly experienced research groups**.
2. Rinieri P, Peillon C, Bessou JP, Veber B, Falcoz PE, Melki J, et al. National review of use of extracorporeal membrane oxygenation as respiratory support in thoracic surgery excluding lung transplantation. Eur J Cardiothorac Surg. 2015;47(1):87–94. https://doi.org/10.1093/ejcts/ezu127.
3. Makdisi G, Makdisi PB, Wang IW. New horizons of non-emergent use of extracorporeal membranous oxygenator support. Ann Transl Med. 2016;4(4):76. https://doi.org/10.3978/j.issn.2305-5839.2016.02.04.
4.• Rosskopfova P, Perentes JY, Ris HB, Gronchi F, Krueger T, Gonzalez M. Extracorporeal support for pulmonary resection: current indications and results. World J Surg Oncol. 2016;14:25. https://doi.org/10.1186/s12957-016-0781-0. **This review reported the current experience of the different extracorporeal device available for the thoracic surgeon and clarify the different indications**.
5.•• Conrad SA, Broman LM, Taccone FS, Lorusso R, Malfertheiner MV, Pappalardo F, et al. The extracorporeal life support organization maastricht treaty for nomenclature in extracorporeal life support. A position paper of the extracorporeal life support organization. Am J Respir Crit Care Med. 2018;198(4):447–51. https://doi.org/10.1164/rccm.201710-2130CP. **Classification system for ECLS nomenclature which provides a standardized foundation for the description of ECLS application, decreasing ambiguity and providing consistency for the comparison of clinical reports**.
6. Brodie D, Slutsky AS, Combes A. Extracorporeal life support for adults with respiratory failure and related indications: a review. JAMA. 2019;322(6):557–68. https://doi.org/10.1001/jama.2019.9302.
7. McRae K, de Perrot M. Principles and indications of extracorporeal life support in general thoracic surgery. J Thorac Dis. 2018;10(Suppl 8):S931-S46. doi:https://doi.org/10.21037/jtd.2018.03.116.
8. Jayaraman AL, Cormican D, Shah P, Ramakrishna H. Cannulation strategies in adult veno-arterial and veno-venous extracorporeal membrane oxygenation: techniques, limitations, and special considerations. Ann Card Anaesth. 2017;20(Supplement):S11–S8. https://doi.org/10.4103/0971-9784.197791.
9. Benazzo A, Schwarz S, Frommlet F, Schweiger T, Jaksch P, Schellongowski P, et al. Twenty-year experience with extracorporeal life support as bridge to lung transplantation. J Thorac Cardiovasc Surg. 2019;157(6):2515–25 e10. https://doi.org/10.1016/j.jtcvs.2019.02.048.
10. Hoetzenecker K, Schwarz S, Muckenhuber M, Benazzo A, Frommlet F, Schweiger T, et al. Intraoperative extracorporeal membrane oxygenation and the possibility of postoperative prolongation improve survival in bilateral lung transplantation. J Thorac Cardiovasc Surg. 2018;155(5):2193–206 e3. https://doi.org/10.1016/j.jtcvs.2017.10.144.
11. Moser B, Jaksch P, Taghavi S, Murakozy G, Lang G, Hager H, et al. Lung transplantation for idiopathic pulmonary arterial hypertension on intraoperative and postoperatively prolonged extracorporeal membrane oxygenation provides optimally controlled reperfusion and excellent outcome. Eur J Cardiothorac Surg. 2018;53(1):178–85. https://doi.org/10.1093/ejcts/ezx212.
12. Rupprecht L, Lunz D, Philipp A, Lubnow M, Schmid C. Pitfalls in percutaneous ECMO cannulation. Heart Lung Vessel. 2015;7(4):320–6.
13. Kazmi SO, Sivakumar S, Karakitsos D, Alharthy A, Lazaridis C. Cerebral pathophysiology in extracorporeal membrane oxygenation: pitfalls in daily clinical management. Crit Care Res Pract. 2018;2018:3237810. https://doi.org/10.1155/2018/3237810.
14. Taghavi S, Jayarajan SN, Mangi AA, Hollenbach K, Dauer E, Sjoholm LO, et al. Examining noncardiac surgical procedures in patients on extracorporeal membrane oxygenation. ASAIO J. 2015;61(5):520–5. https://doi.org/10.1097/MAT.0000000000000258.
15. Ius F, Tudorache I, Warnecke G. Extracorporeal support, during and after lung transplantation: the history of an idea. J Thorac Dis. 2018;10(8):5131–48. https://doi.org/10.21037/jtd.2018.07.43.
16. Aigner C, Wisser W, Taghavi S, Lang G, Jaksch P, Czyzewski D, et al. Institutional experience with extracorporeal membrane oxygenation in lung transplantation. Eur J Cardiothorac Surg. 2007;31(3):468–73; discussion 73–4. https://doi.org/10.1016/j.ejcts.2006.11.049.
17. Xu L, Li X, Xu M, Gao C, Zhu J, Ji B. Perioperative use of ECMO during double lung transplantation. ASAIO J. 2009;55(3):255–8. https://doi.org/10.1097/MAT.0b013e3181a05795.
18.• Hoetzenecker K, Klepetko W, Keshavjee S, Cypel M. Extracorporeal support in airway surgery. J Thorac Dis. 2017;9(7):2108–17. doi:https://doi.org/10.21037/jtd.2017.06.17. **This review described the published experience of ECLS in airway surgery both in adults and in pediatric patients. It highlights currently available devices and their indications**.
19. Lang G, Ghanim B, Hotzenecker K, Klikovits T, Matilla JR, Aigner C, et al. Extracorporeal membrane oxygenation support for complex tracheo-bronchial procedures†. Eur J Cardiothorac Surg.

2015;47(2):250–5; discussion 6. https://doi.org/10.1093/ejcts/ezu162.

20. Johnson AP, Cavarocchi NC, Hirose H. Ventilator strategies for VV ECMO management with concomitant tracheal injury and H1N1 influenza. Heart Lung Vessel. 2015;7(1):74–80.
21. Kim CW, Kim DH, Son BS, Cho JS, Kim YD. I H et al. The feasibility of extracorporeal membrane oxygenation in the variant airway problems. Ann Thorac Cardiovasc Surg. 2015;21(6):517–22. https://doi.org/10.5761/atcs.oa.15-00073.
22. Keeyapaj W, Alfirevic A. Carinal resection using an airway exchange catheter-assisted venovenous ECMO technique. Can J Anaesth. 2012;59(11):1075–6. https://doi.org/10.1007/s12630-012-9773-x.
23. Redwan B, Ziegeler S, Freermann S, Nique L, Semik M, Lavae-Mokhtari M, et al. Intraoperative veno-venous extracorporeal lung support in thoracic surgery: a single-centre experience. Interact Cardiovasc Thorac Surg. 2015;21(6):766–72. https://doi.org/10.1093/icvts/ivv253.
24. Grapatsas K, Schmid S, Haager B, Loop T, Passlick B. Short veno-venous extracorporeal membrane oxygenation assisted segmentectomy for second primary lung tumor in a patient with insufficient respiratory function for one lung ventilation. Respir Med Case Rep. 2018;24:176–8. https://doi.org/10.1016/j.rmcr.2018.05.027.
25. Felten ML, Michel-Cherqui M, Puyo P, Fischler M. Extracorporeal membrane oxygenation use for mediastinal tumor resection. Ann Thorac Surg. 2010;89(3):1012. https://doi.org/10.1016/j.athoracsur.2009.09.064.
26. Thiagarajan RR, Barbaro RP, Rycus PT, McMullan DM, Conrad SA, Fortenberry JD, et al. Extracorporeal life support organization registry international report 2016. ASAIO J. 2017;63(1):60–7. https://doi.org/10.1097/MAT.0000000000000475.
27. Aubron C, DePuydt J, Belon F, Bailey M, Schmidt M, Sheldrake J, et al. Predictive factors of bleeding events in adults undergoing extracorporeal membrane oxygenation. Ann Intensive Care. 2016;6(1):97. https://doi.org/10.1186/s13613-016-0196-7.
28. Cavayas YA, Del Sorbo L, Fan E. Intracranial hemorrhage in adults on ECMO. Perfusion. 2018;33(1_suppl):42–50. doi:https://doi.org/10.1177/0267659118766435.
29. Kalbhenn J, Schlagenhauf A, Rosenfelder S, Schmutz A, Zieger B. Acquired von Willebrand syndrome and impaired platelet function during venovenous extracorporeal membrane oxygenation: rapid onset and fast recovery. J Heart Lung Transplant. 2018;37(8):985–91. https://doi.org/10.1016/j.healun.2018.03.013.
30. Kalbhenn J, Wittau N, Schmutz A, Zieger B, Schmidt R. Identification of acquired coagulation disorders and effects of target-controlled coagulation factor substitution on the incidence and severity of spontaneous intracranial bleeding during veno-venous ECMO therapy. Perfusion. 2015;30(8):675–82. https://doi.org/10.1177/0267659115579714.
31. Krueger K, Schmutz A, Zieger B, Kalbhenn J. Venovenous extracorporeal membrane oxygenation with prophylactic subcutaneous anticoagulation only: an observational study in more than 60 patients. Artif Organs. 2017;41(2):186–92. https://doi.org/10.1111/aor.12737.
32. Broman LM, Malfertheiner MV, Montisci A, Pappalardo F. Weaning from veno-venous extracorporeal membrane oxygenation: how I do it. J Thorac Dis. 2018;10(Suppl 5):S692-S7. doi: https://doi.org/10.21037/jtd.2017.09.95.