Extracorporeal life support use in limited lung function: a narrative review

João Santos Silva[1], Daniel Cabral[2], Paulo Almeida Calvinho[1], Anne Olland[3,4,5], Pierre-Emmanuel Falcoz[3,4,5]

[1]Serviço de Cirurgia Cardiotorácica, Hospital de Santa Marta, Centro Hospitalar Universitário Lisboa Central, Lisbon, Portugal; [2]Serviço de Cirurgia Torácica, Hospital Pulido Valente, Centro Hospitalar Lisboa Norte, Lisbon, Portugal; [3]Hôpitaux Universitaire de Strasbourg, Service de chirurgie thoracique-Nouvel Hôpital Civil, Strasbourg, France; [4]INSERM (French National Institute of Health and Medical Research), UMR 1260, Regenerative Nanomedicine (RNM), Fédération de Médecine Translationnelle de Strasbourg (FMTS), Strasbourg, France; [5]Université de Strasbourg, Faculté de médecine et pharmacie, Strasbourg, France

Contributions: (I) Conception and design: All authors; (II) Administrative support: PE Falcoz; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: J Santos Silva, D Cabral; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Pierre-Emmanuel Falcoz, PhD. Hôpitaux Universitaire de Strasbourg, Service de Chirurgie Thoracique-Nouvel Hôpital Civil, Strasbourg, France; INSERM (French National Institute of Health and Medical Research), UMR 1260, Regenerative Nanomedicine (RNM), Fédération de Médecine Translationnelle de Strasbourg (FMTS), Strasbourg, France; Université de Strasbourg, Faculté de médecine et pharmacie, Strasbourg, France; Department of Thoracic Surgery, Nouvel Hôpital Civil, Hôpitaux Universitaires de Strasbourg, 1 Place de l'Hôpital, BP 426, 67091 Strasbourg Cedex, France. Email: pierre-emmanuel.falcoz@wanadoo.fr.

Background and Objective: In thoracic surgery, different modalities of extracorporeal life support (ECLS) can be used for cardiorespiratory support in complex scenarios. Decades of learning in clinical practice and physiology associated with technological development led to a great variety of ECLS technologies available. Thoracic surgery procedures with difficult or impossible single lung ventilation may still be performed using different ECLS modalities. The aim of this review is to describe the use of ECLS, with its different modalities, as a solution to perform complex surgeries in a patient with difficult or impossible single lung ventilation.

Methods: A literature review was conducted using the terms "extracorporeal life support pulmonary resection" and "extracorporeal life support thoracic surgery", and articles were selected according to defined criteria.

Key Content and Findings: To support lung function during thoracic surgery, the most efficient and popular variety of ECLS is venovenous extracorporeal membrane oxygenation. Lung resection on a single lung after pneumonectomy, surgery in a patient with severe hypercapnia and/or low respiratory reserve, carinal and airway surgery, and severe thoracic trauma are the main examples of situations where ECLS may be the solution to provide a safe surgical environment in patients who cannot tolerate single lung ventilation. Multidisciplinarity, selection of patients and careful surgical planning are cornerstones in defining the situations that may benefit from ECLS support.

Conclusions: Knowledge on techniques of ECLS are essential for every thoracic surgeon. Although rarely used, these techniques of cardiorespiratory support should be considered when planning complex cases with difficulties in ventilation and emergent situations.

Keywords: Extracorporeal; extracorporeal membrane oxygenation (ECMO); cannulation; thoracic surgery; lung function

Submitted Oct 03, 2022. Accepted for publication Jul 14, 2023. Published online Jul 27, 2023.
doi: 10.21037/jtd-22-1364
View this article at: https://dx.doi.org/10.21037/jtd-22-1364

Introduction

Background

In general thoracic surgery, adequate ventilation is essential to provide good oxygenation and carbon dioxide removal. The lung is the central organ of ventilation and in the case of complex procedures, ventilation with one lung may be insufficient.

Extracorporeal life support (ECLS) in general thoracic surgery is becoming increasingly frequent and may play a vital role in offering surgery in the most complex scenarios.

Over the past decades, ECLS has strongly evolved, and better outcomes are reported as a consequence of more biocompatible devices and increased experience in clinical practice (1,2).

Several modalities of ECLS are available for general thoracic surgery, depending on the goal. But globally, the purpose of ECLS is to provide oxygenation and/or ventilation through an oxygenation membrane, with or without circulatory assistance, with a drainage (outflow) cannula and an inflow cannula to pump it back to the patient. Although drainage is typically through a vein (e.g., venous drainage cannula), alternative strategies including pulmonary artery or transeptal or direct atrial approaches are all feasible.

Rationale and knowledge gap

Although widely described and employed in different scenarios, variants of ECLS are (3) have different purposes and are used in different scenarios such as cardiorespiratory failure, cardiac surgery or during lung transplantation.

However, the use of ECLS in general thoracic surgery is infrequently described. Some examples may be airway surgery, carinal resection, central tumors with heart invasion, or scenarios where single lung ventilation is insufficient to perform the proposed procedure. Several modalities of ECLS are available to increase safety in general thoracic surgery (3). Rare situations of thoracic trauma may benefit from ECLS (4).

Securing the airway and ventilation may pose a major challenge during thoracic surgery. Different scenarios impose different solutions, from surgery on the tracheobronchial tree to lung resection in patients with severe respiratory insufficiency; several solutions have been described. Tracheostomy cannula, cross-field ventilation, jet ventilation, and small bore endotracheal tubes are all techniques that can be used. However, there are still circumstances when they may fail and ECLS is the remaining solution. The major advantage of ECLS is to provide oxygenation to allow for a safe procedure, with a surgical site clean from tubes, facilitating exposure and dissection, and, if needed, provide cardiocirculatory support (5).

Venovenous (VV)-extracorporeal membrane oxygenation (ECMO) is probably the most popular modality of ECLS during general thoracic surgery. It has been described as providing intra-operative support in a variety of procedures, such as decortication of empyema (6), thoracoscopic bullectomy (7), thoracoscopic surgery in the single lung patient (8), bilateral lavage for alveolar proteinosis (9), metastasectomy following previous lung resection (10) or robotic-assisted lobectomy in a patient with severe emphysema that prohibited single lung ventilation (11).

Objective

This narrative review aims to address the rationale for peri-operative support in patients submitted to general thoracic surgery in whom single lung ventilation is difficult or impossible. We divided the paper into two sections: First, we describe ECLS modalities and, secondly, we discuss specific scenarios of difficult or impossible sing lung ventilation. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-1364/rc).

Methods

Library searches of the PubMed database were conducted in August 2022. The search query was "extracorporeal life support pulmonary resection" and "extracorporeal life support thoracic surgery", with 162 and 4,871 results, respectively.

No time limit was added or exclusion based on language. All study types were considered, and only published papers were selected.

The results were reviewed by the authors, and articles were selected manually to be included in this narrative review. References from selected articles were looked up and added if considered suitable to the manuscript.

Search method was summarized in *Table 1*.

Overview of ECLS modalities

ECLS techniques mostly used in general thoracic surgery are (12):

Table 1 Summary of search methods

Items	Specification
Date of search	August 2022
Databases and other sources searched	PubMed
Search terms used	"Extracorporeal life support pulmonary resection"; "extracorporeal life support thoracic surgery"
Timeframe	No time frame applied
Exclusion criteria	Abstracts not published were excluded
Selection process	Authors selected articles and references were looked up as appropriate

(I) Extracorporeal membrane oxygenation;
(II) Classic cardiopulmonary bypass (CPB);
(III) Extracorporeal CO_2 removal ($ECCO_2R$).

Extracorporeal membrane oxygenation

ECMO is the most commonly used ECLS modality in general thoracic surgery (3,13). It consists on a drainage cannula, to drain the venous blood connected to a pump. This pump will force the blood through a membrane oxygenator. Finnally, an inflow cannula will inject blood to the patient. Two variants may be used: VV-ECMO or venoarterial ECMO (VA-ECMO) (3,12). VV-ECMO will provide respiratory support while VA-ECMO has the advantage of providing respiratory and cardiocirculatory support as well.

The ECMO system may be peripheral, when jugular or femoral vessels are cannulated, or central when the cannulated sites are mediastinal great vessels, such as the aorta, atrium, vena cava, subclavian artery and vein or pulmonary artery.

Venovenous extracorporeal membrane oxygenation

VV-ECMO represents the gold standard for severe and refractory respiratory failure (12,14). It is the most frequently used ECLS modality in general thoracic surgery (3,12).

An inflow cannula in a peripheral or central vein will lead to oxygenated blood being given to the native lungs of the patient. This will provide the advantage of offering optimal oxygenation of the lungs, heart and brain. Additionally, it will reduce pulmonary vascular resistance and open the possibility for a protective mechanical ventilation strategy if needed (15-17).

This modality tolerates a lower anticoagulation time (ACT). An ACT >200 seconds is recommended at cannulation, but afterward it can be lowered to 160 seconds. In extreme bleeding-related scenarios, it can be stopped for up to 24–72 h (12).

Usually, this modality is achieved through double cannulation using one femoral vein and the internal right jugular vein. However, 1 dual-lumen cannula in the right internal jugular vein gained popularity during the recent coronavirus pandemic due to the advantage of facilitating awake ECMO support by enabling extubation, patient mobilization, rehabilitation, and increasing patient comfort (12). Although very popular in acute respiratory failure, this modality is rarely used for intraoperative support.

VV-ECMO using double cannulation of the femoral veins is also an option, although caution is advised due to a possible higher incidence of recirculation and groin infection.

Venoarterial extracorporeal membrane oxygenation

This modality is used for cardiocirculatory support with or without respiratory failure. Cardiocirculatory support will be dependent on the flow and peripheral resistances. Therefore, the inflow cannula should be large enough to provide superior flow than the patient's cardiac output.

This modality requires higher anticoagulation compared with VV variant, but ACT times required are between 180 and 200 seconds, still lower than classic CPB.

Cardiopulmonary bypass

Classic CPB represents the most widely used ECLS technique due to its role during cardiac surgery (3,12).

In general thoracic surgery, it is the most appropriate modality that allows for the opening of cardiac cavities invaded by the tumor for resection and reconstruction.

Depending on the surgical scenario, tumor location, and need for reconstruction, the cannula's position may differ. Superior or inferior vena cava and the right atrium will be effective for the venous drainage (3,18). Arterial inflow cannula, if the ascending aorta is not accessible may be achieved using the femoral artery (3,18).

The use of ECMO during general thoracic surgery decreased the use of CPB for intraoperative support. Recent papers documented better perioperative management and reduced postoperative complications with the use of ECMO (19-21). Other reports show a survival benefit in favor of ECMO compared with CPB (20,21), while another report showed reduced postoperative complications, although no difference in survival (19).

Extracorporeal CO_2 removal

$ECCO_2R$ provides support to patients suffering from hypercapnic respiratory failure, by using an extracorporeal shunt and CO_2 removal membrane, in which lower flow rates (200–1,500 mL) are used to remove the circulating CO_2. The rationale of this low blood flow relies on the fact that 1 L of blood with a $PaCO_2$ of 40 mmHg contains around 500 mL of CO_2. Accounting for a patient's production of 300 mL of CO_2 per minute, it would be enough a blood flow of 1 L to remove all patients CO_2 production and be able to perform a protective ventilation (22).

This can be done either through VV or arterio-venous (AV) $ECCO_2R$. The VV $ECCO_2R$ supports the inflow through an external pump and is normally used in patients with impaired heart function while the pumpless AV $ECCO_2R$ relies on the patient's native cardiac function (23). Traditionally AV $ECCO_2R$ were used, although vascular complications and the spread use of conventional ECMO due to coronavirus disease 2019 (COVID-19) pandemic brought us a shift towards VV $ECCO_2R$, although Yu *et al.* in his systematic review and meta-analyses didn't find any statistical differences between both strategies regarding hypercapnia correction and patient mortality (23).

There are several modalities of cannulation, being used smaller cannulas than the ones used for conventional ECMO (13 to 18 Fr), making sure that they fill around 70% of the cannulated vessel. Smaller cannulae have the potential benefit of decreasing cannulation-related complications. However, it is out of the scope of this text to go further in detail in technique strategies for this procedure.

The most common indication for this technique is acute hypercapnic respiratory failure in the setting of COPD, severe acute asthma patients and hypercapnic patients with respiratory acidosis as bridge/recovery for lung transplantation and its use in the context of thoracic surgery is seldom hypercapnia (12,13,17,22,23).

Complications of ECLS modalities

One of the most common complications of every ECLS technique is hemorrhage, even with lower anticoagulation need during ECMO (3), with reported rates of reoperation due to bleeding after lung resection with ECLS between 10% to 21% of patients. Careful dissection and adhesions breakdown is recommended to be carried out before cannulation in order to lower the risk (18).

Femoral cannulation is associated with groin infection, especially during long-term VV-ECMO support (3,12).

CPB is the ECLS modality that will induce the greatest inflammatory response and hemolysis, and also confers a higher risk of lung injury. Lung injury and acute respiratory distress syndrome (ARDS) are known risks, reaching rates as high as 37% when lung resection is associated, with pneumonectomy and prolonged CPB time as known risk factors. A 22% mortality rate after pneumonectomy was reported (24), compared with 0% after lobectomy.

ECMO may be preferred over CPB during general thoracic surgery due to a decreased complication rate, mainly bleeding issues, as reported in the literature (18,21,25).

Stroke or acute renal failure are also known complications. The literature regarding its incidence in general thoracic surgery is scarce. However, it is believed to be less frequent than after cardiac surgery (18).

Dissemination of tumor cells is a theoretical risk of any ECLS modality, due to immune system dysregulation or re-circulation of aspirated blood from the operative field. However, no current scientific evidence supports this theory (18). The need for ECLS in the resection of thoracic tumors usually indicates a more advanced stage of the disease which confers a higher secundarization risk *per se*.

Difficult/impossible single lung ventilation scenarios

During general thoracic surgery, the use of ECLS techniques has two main purposes: to enable technical resectability and to provide support to improve functional operability. Regarding resectability, the use of ECLS techniques will provide a cardiorespiratory function to enable resection and reconstruction of the airway or in the presence of cardiac invasion. The technique selection will depend on the particular scenario, bearing in mind that surgery with the opening of any heart chamber will require CPB. Regarding functional operability, ECLS may provide

Table 2 Summary of limited ventilation lung function and ventilation

Scenario	Obstacles	ECLS preferable tool	Objective	Comment
One lung surgery	Perform lung resection surgery in the patient with one lung	VV-ECMO; VA-ECMO if hemodynamic instability	Allow VATS surgery in the post-pneumonectomy patients	ECMO support will allow gas exchange during lung resection surgery with the lung collapsed
Inadequate ventilation	Low respiratory reserve and/or severe hypercapnia	VV-ECMO	Ensure oxygenation and decarboxylation during intraoperative period	Assuring oxygenation during perioperative period results in good surgical outcomes in high-risk patients
Carinal and tracheal surgery	Airway instrumentation	VV-ECMO; VA-EMCO if scenario includes heart mobilization or complex resections	Allow gas exchange during airway resection and reconstruction	Cross field and jet ventilation are less invasive alternatives and ECLS techniques are reserved for cases when those alternatives are insufficient
Trauma	Variability of lesion according with the trauma mechanism	VV-ECMO; VA-ECMO if hemodynamic instability	Ventilatory stabilization prior and during surgical approach	Life threatening compromise of the airway and ventilation with need for surgical correction may need ECLS to assure conditions to support intraoperative period

ECLS, extracorporeal life support; VV, venovenous; ECMO, extracorporeal membrane oxygenation; VA, venoarterial.

intraoperative support for both cardiocirculatory and pulmonary function, allowing the extension of the benefit of surgical approach in selected patients.

In the following section, we will describe several scenarios of impaired or limited lung ventilation and respiratory function in which ECLS techniques may provide additional value to increase operability and safety. In the end, the scenarios will be summarized in *Table 2*.

One-lung surgery

One of the most challenging situations is approaching a post-pneumonectomy patient. Plenty of reasons could demand a pneumonectomy but taking into account the oncological setting, it is widely known that patients with lung cancer are at risk of developing a second primary lung cancer or a recurrence of the previous one (8).

Several reports concerning lung surgery in post-pneumonectomy patients are present in the literature (8,26,27). Surgical treatment should not be promptly excluded, and various options must be considered, like high-frequency jet ventilation, periodical apneas, or the use of CO_2 in the pleural cavity (8,26,28). Single lung surgery with high oxygen flow associated with tidal volume may provide up to 30 min of surgery with safe oxygenation, which may be sufficient for simple procedures on patients with one lung. However, both options have some constraints. Apnea with high-flow oxygen may lead to severe hypercapnia and respiratory acidosis (28).

There could be difficulty in deflating the lung or getting access to the pleural cavity due to adhesions. It may oblige open procedures to get a shorter duration and facilitate the manipulation of an inflated lung. A clear distinction should be made between the need for a wedge resection of a peripheral lesion, or a central lesion with need of an anatomical resection, such as segmentectomy, in which ECMO support will probably be needed (8). It allows for maintaining gas exchange with a collapsed lung (26), providing a clear surgical field, a less stressful procedure, and the possibility of a minimally invasive surgical approach by VATS. In fact, knowing the respiratory mechanical alterations related to thoracotomy, VATS might be of foremost interest in this group of single-lung patients (8). ECMO is a reliable option, even more in more complex procedures or if other obstacles are previously anticipated. Post-pneumonectomy alterations do not restrict to the respiratory system. The cardio-vascular system is also affected. Once more, VA-ECMO, could be essential to maintain hemodynamic stability and overcome possible problems.

Inadequate ventilation

Lung resection surgery in patients with low respiratory reserve, usually associated with severe hypercapnia, is still a matter of debate. Patients with low respiratory reserve should be carefully evaluated and selected for surgical treatment, and alternative treatments and/or medical optimization should be explored as much as possible before offering such patients a high-risk procedure.

The most frequent scenario is the patient with severe emphysema and hypercapnia that may or not be a candidate for lung volume reduction surgery (LVRS).

After the NETT trial, severe hypercapnia ($PaCO_2$ >55 mmHg) has become an exclusion criterion for LVRS (29,30). However, some papers still debate the risk/benefit ratio for LVRS in highly selected patients that may benefit from LVRS even in this scenario (31-33).

ECLS may be a valuable tool to manage severe hypercapnia during LVRS in carefully selected patients that may benefit from the procedure.

The main goal of ECLS in this scenario is the removal of CO_2. Therefore, the preferred modalities will be VV-ECMO and $ECCO_2R$.

A German study conducted by Akil *et al.* (32) reported 65 cases of LVRS under ECLS, all patients with VV modality and VATS surgery and compared with a control group of 60 normocapnic patients submitted to the same procedure. The group reported a mortality rate at 90 days of 7.8% in the study group *vs.* 5% of the control group and, globally, they concluded that LVRS in patients with severe hypercapnia under ECLS support is effective and well tolerated and also increases safety during surgery, supports ventilation decalation and reduces the rate of immediate postoperative complications.

A series from China (31) reported 15 cases of patients with severe hypercapnia submitted to LVRS with 1 case of need for VV-ECMO support. The authors also concluded that this group of patients may still benefit from the procedure.

Globally, patients previously considered high risk in the literature (29,30) may still be considered for surgery if there is a benefit. To go through the procedure safely may be achieved by using an appropriate ECLS modality.

Another subset of patients that may not tolerate single lung ventilation is those patient with bilateral empyema submitted to surgery or complications from pneumonia. ECMO support, ideally VV, is used to support oxygenation while waiting for the lung to recover. Surgery may be indicated for decortication or excision of the necrotic lung to improve the chance of recovery and has been reported to be done under ECMO support (6,34).

Carinal and tracheal surgery

Carinal, tracheoesophageal fistulas and tracheal stenosis resections and reconstructions are often demanding procedures.

In the literature, the use of ECMO for this kind of surgeriy is fairly reported (3,35). High-frequency jet ventilation or cross-field intubation are valuable options and in straightforward cases might be the best option. However, some limitations must be acknowledged. Multidisciplinarity with good collaboration between the surgical and the anesthetic team is essential, with careful preoperative surgical planning. But in some cases, it may be difficult to ensure a secure airway and to avoid hypercapnia or barotrauma (28). VV-ECMO should be kept in mind by every thoracic surgeon as a concrete option owing special advantages when the main goal is to provide good oxygenation. Other advantages include keeping the surgical field clear of tubes, facilitating visualization, dissection, and reconstruction (5,35), and managing complications such as or barotrauma of the contralateral lung.

In this scenario, VA-ECMO is reserved for cases where complex resections and reconstructions are predicted with the need for heart retraction, which can cause hemodynamic compromise (5), or any other scenario with unpredicted hemodynamic instability.

Trauma

Traumatic injuries of the trachea and proximal tracheobronchial tree are challenging situations in which ECMO is also of foremost interest, not only during the surgical procedure but also before and after that (5). The decision of the ECLS modality in the intraoperative period to better fit each situation will depend on the most important injury to repair, hemodynamic instability, and respiratory insufficiency. To allow for postoperative support, ECMO is the best option. Preferably, VV-ECMO if no hemodynamic instability is present. This subject will be further discussed in other papers.

Iatrogenic injuries to the trachea, although rare and most frequently requiring only a conservative approach, may present life-threatening compromise of the airway and ventilation (36). In this scenario, the choosen modality will have to offer pre-operative stabilization and respiratory support during surgery. Therefore, VV-ECMO will be the most indicted modality (37-39).

Discussion

Although ECLS techniques are invaluable tools to achieve success in complex thoracic procedures, the decision to initiate any technique should not be taken lightly.

A balance between risk and benefit should be considered, associated with careful preoperative planning.

Less invasive tools are available and may replace the need for ECLS in some scenarios. Cross fields and jet ventilation are examples of techniques more frequently employed during thoracic surgery.

ECLS techniques, despite the advantages, add risk and complications to any procedure due to their invasive nature. Naturally, complex procedures requiring ECLS support will have an increased risk associated with the underlying disease and patient factors and related to the ECLS support technique. The most common complication of every ECLS modality is hemorrhage, with an incidence of 10% to 30% (5). It is more frequent when CPB or VA-ECMO are used due to increased demands of anticoagulation. Additional risks include cannulation-related risks, such as embolization, aneurysm, dissection; neurological complications that include hemorrhage, infarction, cerebral oedema and seizures; infection; renal failure or gastrointestinal complications (5). Careful selection of patients, ECLS modality selection, and careful preoperative planning including both surgical, anesthesiology, and postoperative care teams is essential to diminish the duration of ECLS and the incidence of complications.

Nevertheless, the authors defend that knowledge of ECLS modalities is vital for any general thoracic surgeon to consider them when planning complex procedures and when alternatives fail. ECLS may become necessary in an emergency setting.

Further studies on the safety and impact of risk or complications of ECLS techniques in general thoracic surgery are strongly encouraged.

Conclusions

Every general thoracic surgeon should have knowledge and experience in ECLS techniques, even if its use is scarce. In complex cases or emergency scenarios, these support options should be considered, so that no surgical treatment is denied in those patients that may benefit from surgery under ECLS.

The most popular technique is VV-ECMO, while VA-ECMO will have an important role when cardiocirculatory support is needed.

The use of ECLS techniques to improve safety during and after general thoracic surgery in patients with a low respiratory reserve and in whom single lung ventilation is not tolerated or impossible may be an efficient and reliable option. The decision should include multidisciplinarity between surgical and anesthesiology teams, careful surgical planning and selection of patients.

Specialized and high-volume surgical centers should concentrate on these particularly challenging patients to achieve the best possible outcomes.

Acknowledgments

Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Ilhan Inci) for the series "Extracorporeal Life Support in Thoracic Surgery" published in *Journal of Thoracic Disease*. The article has undergone external peer review.

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-1364/rc

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-1364/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-1364/coif). The series "Extracorporeal Life Support in Thoracic Surgery" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. MacLaren G, Combes A, Bartlett RH. Contemporary extracorporeal membrane oxygenation for adult respiratory failure: life support in the new era. Intensive Care Med 2012;38:210-20.
2. Thiagarajan RR, Barbaro RP, Rycus PT, et al. Extracorporeal Life Support Organization Registry International Report 2016. ASAIO J 2017;63:60-7.
3. Santos Silva J, Pinheiro Santos J, Calvinho PA, et al. Cannulation strategies for intraoperative mechanical cardio-respiratory support in general thoracic surgery. Curr Chall Thorac Surg 2023;5:30.
4. Lang NW, Schwihla I, Weihs V, et al. Survival rate and Outcome of extracorporeal life support (ECLS) for treatment of acute cardiorespiratory failure in trauma patients. Sci Rep 2019;9:12902.
5. Eadington T, Oommen K. The role of extracorporeal membrane oxygenation in thoracic surgery—a narrative review. Shanghai Chest 2022;6:22.
6. Brenner M, O'Connor JV, Scalea TM. Use of ECMO for resection of post-traumatic ruptured lung abscess with empyema. Ann Thorac Surg 2010;90:2039-41.
7. Redwan B, Biancosino C, Giebel F, et al. Perioperative single-site veno-venous extracorporeal CO(2) removal for minimally invasive giant bulla resection. Perfusion 2017;32:698-701.
8. Lo Iacono G, Bertolaccini L, Petrella F, et al. Lung resection after pneumonectomy: the pivotal role of extracorporeal membrane oxygenation—a case report. J Vis Surg 2020;6:33.
9. Krecmerova M, Mosna F, Bicek V, et al. Extracorporeal membrane oxygenation to support repeated whole-lung lavage in a patient with pulmonary alveolar proteinosis in life threatening dyspnoe--a case report. BMC Anesthesiol 2015;15:173.
10. Redwan B, Ziegeler S, Freermann S, et al. Intraoperative veno-venous extracorporeal lung support in thoracic surgery: a single-centre experience. Interact Cardiovasc Thorac Surg 2015;21:766-72.
11. Rocha Júnior E, Mingarini Terra R, Guerreiro Cardoso PF, et al. Robotic Lung Volume Reduction Surgery With Extracorporeal Membrane Oxygenation. Ann Thorac Surg 2022;114:e351-4.
12. Reeb J, Olland A, Renaud S, et al. Vascular access for extracorporeal life support: tips and tricks. J Thorac Dis 2016;8:S353-63.
13. Reeb J, Olland A, Massard G, et al. Extracorporeal life support in thoracic surgery. Eur J Cardiothorac Surg 2018;53:489-94.
14. Makdisi G, Wang IW. Extra Corporeal Membrane Oxygenation (ECMO) review of a lifesaving technology. J Thorac Dis 2015;7:E166-76.
15. Brodie D, Bacchetta M. Extracorporeal membrane oxygenation for ARDS in adults. N Engl J Med 2011;365:1905-14.
16. Del Sorbo L, Cypel M, Fan E. Extracorporeal life support for adults with severe acute respiratory failure. Lancet Respir Med 2014;2:154-64.
17. Gattinoni L, Kolobow T, Damia G, et al. Extracorporeal carbon dioxide removal (ECCO2R): a new form of respiratory assistance. Int J Artif Organs 1979;2:183-5.
18. Dartevelle P, Fadel E. Extended Thoracic Resections with Cardiopulmonary Bypass. In: Mathisen DJ, Morse C. Master Techniques in Surgery: Thoracic Surgery II. 1st ed. Lippincott Williams & Wilkins; 2014:433-44.
19. Biscotti M, Yang J, Sonett J, et al. Comparison of extracorporeal membrane oxygenation versus cardiopulmonary bypass for lung transplantation. J Thorac Cardiovasc Surg 2014;148:2410-5.
20. Ius F, Kuehn C, Tudorache I, et al. Lung transplantation on cardiopulmonary support: venoarterial extracorporeal membrane oxygenation outperformed cardiopulmonary bypass. J Thorac Cardiovasc Surg 2012;144:1510-6.
21. Machuca TN, Collaud S, Mercier O, et al. Outcomes of intraoperative extracorporeal membrane oxygenation versus cardiopulmonary bypass for lung transplantation. J Thorac Cardiovasc Surg 2015;149:1152-7.
22. Combes A, Brodie D, Aissaoui N, et al. Extracorporeal carbon dioxide removal for acute respiratory failure: a review of potential indications, clinical practice and open research questions. Intensive Care Med 2022;48:1308-21.
23. Yu TZ, Tatum RT, Saxena A, et al. Utilization and outcomes of extracorporeal CO(2) removal (ECCO(2) R): Systematic review and meta-analysis of arterio-venous and veno-venous ECCO(2) R approaches. Artif Organs 2022;46:763-74.
24. Wiebe K, Baraki H, Macchiarini P, et al. Extended pulmonary resections of advanced thoracic malignancies with support of cardiopulmonary bypass. Eur J Cardiothorac Surg 2006;29:571-7; discussion 577-8.
25. Zangrillo A, Garozzo FA, Biondi-Zoccai G, et al. Miniaturized cardiopulmonary bypass improves short-term outcome in cardiac surgery: a meta-analysis of randomized controlled studies. J Thorac Cardiovasc Surg 2010;139:1162-9.

26. Lei J, Su K, Li XF, et al. ECMO-assisted carinal resection and reconstruction after left pneumonectomy. J Cardiothorac Surg 2010;5:89.
27. Owada-Ozaki Y, Matsumura Y, Suzuki H. VV-ECMO during subsequent segmentectomy after right pneumonectomy. J Surg Case Rep 2018;2018:rjy213.
28. Suk P, Šrámek V, Čundrle I Jr. Extracorporeal Membrane Oxygenation Use in Thoracic Surgery. Membranes (Basel) 2021;11:416.
29. Fishman A, Martinez F, Naunheim K, et al. A randomized trial comparing lung-volume-reduction surgery with medical therapy for severe emphysema. N Engl J Med 2003;348:2059-73.
30. National Emphysema Treatment Trial Research Group; Fishman A, Fessler H, et al. Patients at high risk of death after lung-volume-reduction surgery. N Engl J Med 2001;345:1075-83.
31. You B, Zhao Y, Hou S, et al. Lung volume reduction surgery in hypercapnic patients: a single-center experience from China. J Thorac Dis 2018;10:S2698-703.
32. Akil A, Ziegeler S, Reichelt J, et al. Veno-Venous Extracorporeal Lung Support as a Bridge to or Through Lung Volume Reduction Surgery in Patients with Severe Hypercapnia. ASAIO J 2020;66:952-9.
33. Redwan B, Ziegeler S, Semik M, et al. Single-Site Cannulation Venovenous Extracorporeal CO2 Removal as Bridge to Lung Volume Reduction Surgery in End-Stage Lung Emphysema. ASAIO J 2016;62:743-6.
34. Bressman M, Raad W, Levsky JM, et al. Surgical therapy for complications of pneumonia on extracorporeal membrane oxygenation can improve the ability to wean patients from support. Heart Lung Vessel 2015;7:330-1.
35. Hoetzenecker K, Klepetko W, Keshavjee S, et al. Extracorporeal support in airway surgery. J Thorac Dis 2017;9:2108-17.
36. Grewal HS, Dangayach NS, Ahmad U, et al. Treatment of Tracheobronchial Injuries: A Contemporary Review. Chest 2019;155:595-604.
37. Antonacci F, De Tisi C, Donadoni I, et al. Veno-venous ECMO during surgical repair of tracheal perforation: A case report. Int J Surg Case Rep 2018;42:64-6.
38. Go PH, Pai A, Larson SB, et al. Repair of iatrogenic tracheal injury in acute respiratory failure with veno-venous extracorporeal membrane oxygenation. Perfusion 2021;36:100-2.
39. Hawkins RB, Thiele EL, Huffmyer J, et al. Extracorporeal membrane oxygenation for management of iatrogenic distal tracheal tear. JTCVS Tech 2020;4:389-91.

Cite this article as: Santos Silva J, Cabral D, Calvinho PA, Olland A, Falcoz PE. Extracorporeal life support use in limited lung function: a narrative review. J Thorac Dis 2023;15(9):5239-5247. doi: 10.21037/jtd-22-1364