Cannulation strategies for intraoperative mechanical cardio-respiratory support in general thoracic surgery

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Abstract: In general thoracic surgery, extracorporeal mechanical cardio-respiratory support (EMCS) techniques are performed intraoperatively mainly for respiratory but also for cardiocirculatory support. The increasing panel of EMCS technologies available in thoracic surgery is the result of a century of clinical practices, engineering progress, and improvements of physiological knowledge. Complex procedures of tumor resection, traqueal and main airway surgery or lung transplantation are the scenarios where these techniques should be considered if needed. The aim of this review is to describe different modalities of EMCS used in general thoracic surgery with a particular attention to the cannulation techniques. Venovenous extracorporeal membrane oxygenation (VV-ECMO) is the most common EMCS modality and represents the most efficient in supporting lung function. Venoarterial ECMO (VA-ECMO) may be achieved in both central and peripheral cannulation. Central VA-ECMO is the main modality for intraoperative emergent support, which brought a decrease in popularity of classic cardiopulmonary bypass (CPB) due to lower risk of complications. Peripheral VA-ECMO is traditionally performed in a femoro-femoral configuration. Extracorporeal CO_2 removal ($ECCO_2R$) and Novalung are marginal alternatives for intraoperative support during general thoracic surgery. Although rarely used, ECMS techniques should be part of every general thoracic surgeon armamentarium and should be brought to mind in complex cases or in emergency settings.

Keywords: Extracorporeal; extracorporeal membrane oxygenation (ECMO); cardiopulmonary bypass (CPB); cannulation; thoracic

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Introduction

The lung is the central organ responsible for the respiratory gas exchange of oxygen and carbon dioxide. Basically, the alveolar interface is a membrane oxygenator between the alveoli and the pulmonary circulation (1).

The use of extracorporeal mechanical cardio-respiratory support (EMCS) in the context of thoracic surgery, lung transplantation and cardiorespiratory failure is becoming increasingly more frequent.

Extracorporeal mechanical life support has strongly evolved over the last years, with better and more biocompatible devices that combined with increased experience in clinical practice led to better outcomes (2,3). EMCS support both the circulation and the respiration using extracorporeal circuits in different ways depending on the goal. In short, there is always a venous drainage with the blood being driven through an oxygenation membrane and pumped again to the patient, with or without circulatory assistance. So, depending on the goal, several techniques of EMCS are available. The most common variants of EMCS are classic cardiopulmonary bypass (CPB) and extracorporeal membrane oxygenation (ECMO) with both venoarterial and venovenous variants.

Globally, the goals of EMCS are: 1—short to mid-term cardiopulmonary support; 2—extracorporeal oxygenation support; 3—extracorporeal carbon dioxide removal.

Its use has been widely described and employed in cardiorespiratory failure, cardiac surgery and lung transplantation but rarely described in perioperative general thoracic surgery. Complex airway surgery with central bronchial reconstruction, surgery in central tumors with heart invasion or in high-risk patients in whom single lung ventilation is not enough to perform the proposed resection, several forms of EMCS might be used in order to accomplish with safety the proposed surgery. In rare situations of thoracic trauma, EMCS can be helpful (4).

This paper will address several modalities of EMCS, their cannulation strategies and their rationale for intra-operative support during general thoracic surgery. The most common complications and results will be discussed here. The strategies and its rationale in lung transplantation are discussed in another chapter.

Overview of EMCS modalities and its cannulation strategies

In thoracic surgery, the EMCS techniques mostly used are: (I) the ECMO; (II) classic CPB; (III) the extracorporeal CO_2 removal ($ECCO_2R$); and (IV) the pumpless device "Novalung" (Novalung GmbH, Hechingen, Germany) (5).

ECMO

This form of EMCS uses a drainage cannula to drain the venous blood from the patient (outflow) connected to a pump that injects the blood through a membrane oxygenator and then to an inflow cannula back to the patient. This inflow cannula can be inserted on a vein (ECMO VV) or an artery (ECMO VA). If the cannulated vessels are peripheral (jugular, femoral) we call them peripheral ECMO. If the cannulated vessels are the aorta, atrium or the vena cava this circuit is called central ECMO.

One of the most common complications is bleeding, even with need for lower target activated clotting time (ACT). Careful dissection before starting EMCS may lower the risk. Nevertheless, reoperation for bleeding after lung resection under EMCS is estimated to be required in 10% to 21% of patients (6).

Venovenous ECMO (VV-ECMO)

VV-ECMO is the most important and frequently used EMCS modality in general thoracic surgery. It is the most efficient tool to provide respiratory support and consists of a circuit in series between the artificial and native lungs and represents the gold standard for severe and refractory respiratory failure (5,7). The oxygenated blood will go through the native lungs and allow optimal oxygenation of the brain, heart and lungs. In this way, it also decreases pulmonary vascular resistance and allow for a protective mechanical ventilation strategy if needed (8-10).

It is an optimal tool to respiratory support during complex surgery of the central airway when other ventilation strategies are not adequate or in the presence of major pulmonary contusion or acute respiratory distress syndrome (ARDS) in severe trauma.

In VV-ECMO, oxygenation and decarboxylation are dissociated. Oxygenation is proportional to the blood flow through the circuit and fraction of oxygen delivered while decarboxylation will depend on the flow of the gas mixture through the membrane.

The need for anticoagulation is lower with this technique, with an ACT >200s at time of cannulation but afterwards can be lowered to 160s or even stopped for a window up to 24–72 h in case of major bleeding issue or severe trauma (5).

The most common approach is percutaneous cannulation with insertion of either two cannulas or one dual-stage cannula in the internal jugular vein.

The double cannulation technique normally uses one of the femoral veins and the right internal jugular vein. This means that the outflow cannula will terminate at the right atrial-inferior vena cava (RA-IVC) junction and the inflow cannula will terminate at the right atrial-superior vena cava junction or within the right atrium.

Femoral-femoral VV-ECMO is also an option, although rarely used and involves the insertion of the outflow cannula up to 5–10 cm below the RA-IVC junction and the tip of the inflow cannula inserted into the right atrium. This configuration may be associated with a higher incidence of recirculation.

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

As an alternative, a single dual lumen cannula can be placed into the right internal jugular vein, using the Seldinger technique. This cannula contains two lumens within one 16–31 Fr cannula and can be placed, making sure that the distal portion of the cannula rests in the inferior vena cava. The main advantages of this cannula are that it may enable extubation, patient mobilization, rehabilitation, increase patient comfort and decrease the infectious potential of groin cannulation. The limitations of this cannula are that it may not be used in patients with small right jugular vein and cannula size may limit ECMO flow (<3 L/min) to allow optimal oxygenation (5) and, with higher flows, may predispose to hemolysis. Although very popular, mainly in bridging to lung transplantation, this modality is rarely used for intraoperative support.

Venoarterial ECMO (VA-ECMO)

VA-ECMO is an EMCS modality that is used for cardiocirculatory support with or without respiratory failure. It will provide excellent respiratory and also cardiac support by decreasing both right and left ventricle preload and increasing left ventricle afterload, mainly in peripheral VA-ECMO.

The cardiocirculatory support will be dependent on both the ECMO flow and peripheral resistances, therefore the arterial (inflow) cannula should be large enough to provide a flow superior to the patient cardiac output and some rheological contraction should be achieved. Anticoagulation is needed in VA-ECMO, with a target ACT lower than classic CPB of 180 to 200 seconds that can be lowered or even temporarily stopped if major bleeding is present.

VA-ECMO can be with central or peripheral configuration.

Central VA-ECMO

Intraoperative support is the main indication for central VA-ECMO, in particularly CPB weaning. Most frequent cannulation sites are the ascending aorta for the inflow cannula and right atrium for outflow cannula, in case of intraoperative need or conversion from classic CPB, the previously inserted cannulas are used.

The cannulas should be fixated with double purse-string sutures.

The main advantage of central VA-ECMO is that the inflow cannula gives full anterograde oxygenated blood to the patient and the disadvantage is that it always requires surgical removal and is associated with a higher risk of bleeding and mediastinitis. It also does not allow for extubation and patient mobilization (11).

In general thoracic surgery, during lung resection surgery for lung cancer, EMCS is rarely needed, being its need estimated in less than 0.1% of the procedures (6). The advantage of surgical resection with need for EMCS should be considered having in mind the associated increase in surgical risk and overall prognosis of the underlying disease. It is common accepted that should only be considered in carefully selected patients with excellent performance status, with no significant comorbidities and lung cancer staged pT4N0 and the aim for R0 resection, or other types of neoplasms that have clear survival advantage after complete resection. In non-small cell lung cancer, the risks for extreme resections should be weighed against the possibility of mass reduction with induction chemo or radiotherapy treatments, or even definitive chemoradiation, depending on the multidisciplinary board discussion and experience of the surgical center.

Central tumors with direct invasion of the heart or great vessels is the main indication for lung resection with VA-ECMO. Its need in this scenario can be predicted in the preoperative planning and small series (12-18) report that the elective use of EMCS was associated with better outcomes than when used in emergent situations, especially for management of major bleeding. These authors report mortality rates between 0% and 15% and R0 resection rates between 53% and 92% (12-18). Regarding long-term survival, Muralidaran *et al.* identified a total of 71 patients, included in 20 different studies, with an overall 5-year survival of 37% and median survival time of 36 months (19).

In this scenario, central VA-ECMO is the most appropriate modality either electively or to control major bleeding problems.

When surgical approach is a right thoracotomy, cannulation can be achieved with inflow cannula in the ascending aorta and outflow cannula in the right atrium.

During a left thoracotomy, cannulation can be achieved through insertion of the inflow cannula in the descending aorta and the outflow cannula in the main pulmonary artery, with the tip directed into the right ventricle. Alternatively, opening of the pericardium and cannulation of the right atrium can be done, although it may be cumbersome and dangerous in emergent situations.

The cannulas should again be fixated with purse-string sutures and it may be helpful to tie an umbilical tape around the cannula and atrial wall to prevent air embolization in the outflow cannula (5). The cannula lumen should be selected according with the patient body surface area but enough to provide an inflow of at least 2.2–2.5 $L/m^2/min$ (11).

Theoretically, any EMCS modality may be associated with risk of systemic tumor dissemination, due to immune system dysregulation or re-circulation of aspirated blood from the operative field, although this only occurs with classic CPB. However, no current scientific evidence supports this theory (6). The need for EMCS in the resection of thoracic tumors usually indicate a more advanced stage of disease or a larger mass in which the risk of secundarization is already high per se.

Peripheral VA-ECMO

This modality is classically accomplished in femoral sites. Traditionally, a surgical open technique was performed (20), but nowadays it is most commonly implanted by a percutaneous technique (21).

The surgical technique for peripheral VA-ECMO begins with a 3–4 cm incision to expose the femoral vessels. A purse string polypropylene suture should be put in place in both the femoral artery and vein. At this point, we should create two separate incision for skin tunneling of the cannula, having in mind the need to keep the tunnel parallel to the vessel in order to avoid distortion or kinking. Before cannulation, heparinization should be initiated with a bolus of 5,000 IU. A modified Seldinger technique should be used for both cannula introduction. First, the vein (25–29 Fr) and then the artery (15–19 Fr). The position of the guidewire should be confirmed with transesophageal echocardiography or fluoroscopy (21).

During left or right thoracotomy, the manipulation of femoral vessels may be cumbersome due to the lateral decubitus positioning. Therefore, this technique, when used in the general thoracic surgery setting, should be electively implanted before positioning and incision.

In peripheral VA-ECMO, the most critical complication of femoral artery cannulation is acute limb ischemia and a distal reperfusion cannula (5–6 Fr) in the superficial femoral artery is always recommended. Alternatively, the use of a smaller cannula may preserve some flow to the limb although it will negatively impact the maximum flow and cardiocirculatory support (5). This is a particular concern specially when the need of the VA-ECMO is expected to be extended.

Arterial dissections or vein injuries may occur. Arterial dissections should be repaired surgically while vein injuries are solved with simple compression.

The percutaneous technique is performed with the Seldinger technique, first in the femoral vein and some authors recommend the contralateral artery (21,22). The use of ultrasound guidance is strongly recommended for vessel puncture and transesophageal echocardiography for cannula placement (21).

Alternative cannulation sites are the subclavian arteries—usually at the right side and a surgical technique is preferred—and jugular veins.

Traditionally, a surgical removal was performed, but nowadays, the use of percutaneous closure devices has proved to be safe and feasible, especially in cannulas under 18 Fr (21,23).

Additional venous drainage may help increase the efficiency a VV- or VA-ECMO circuit:

- ❖ VV-A ECMO is the addition of a venous cannula to a peripheral VA-ECMO circuit with the aim of compensating for insufficient backflow;
- ❖ V-AV ECMO is the addition of a second injection cannula to a previous VV- or VA-ECMO circuit to add circulatory support or improve oxygenation of vital organs.

Most mediastinal tumors are resecable without EMCS, even when the superior vena cava is invaded. However, in certain situation that require more complex reconstructions, present with invasion of the right atrium or when the mass cause compression of the right heart with hemodynamic instability, EMCS may help to achieve a complete resection. These tumors are usually approached by median sternotomy or clamshell incisions (6).

Classic CPB or ECMO may be used. Usually, access to centra cannulation may be blocked by the tumor or provide operative field conflict. Therefore, peripheral cannulation may be preferred with the arterial canula in the femoral artery to clear the operative field. The venous cannula should be placed in the right atrium, although some tumors that present with right atrial invasion will require classic CPB with bicaval cannulation (6).

CPB

Classic CPB represents the most widely used EMCS in cardiac surgery. It provides optimal cardiocirculatory and respiratory support. It allows for aortic clamping and cardioplegia, being mandatory for opening and reconstructing the cardiac cavities in the scenario of complex resections of lung tumors invading the heart or great vessels.

Comparing with central VA-ECMO, CPB induces a more intense inflammatory response and hemolysis and needs a higher level of heparinization. It is also the technique with higher risk of lung injury.

Classic CPB is known to induce lung injury and ARDS, and this risk is increased when lung resection is associated, being reported to be as high as 37%. Pneumonectomy and prolonged time under EMCS are associated with higher risk. Wiebe *et al.* (18) reported a 22% mortality rate after pneumonectomy compared with 0% after lobectomy. ECMO seems to have a lower risk than CPB due to a lower inflammatory response (6,24,25).

Stroke or acute renal failure are frequent complications, although it is believed to be less common in general thoracic surgery due to the absence of intra-cardiac manipulation and aortic clamping when compared with classic cardiac surgery (6).

Depending on the surgical scenario and need for reconstruction, the venous cannula may be placed directly in the right atrium, superior or inferior vena cava.

Arterial cannulation in the femoral artery is an alternative when the ascending aorta presents with severe calcifications or the localization of the tumor does not allow for safe cannulation in the ascending aorta.

The popularity of classic CPB for intraoperative support during general thoracic surgery, especially lung transplantation, has decreased due to the evidence suggesting advantages of VA-ECMO in this scenario. Recent papers documented that intraoperative ECMO allows for better periprocedural management and reduced postoperative complications and primary graft dysfunction (24,26,27) and some reports show a survival benefit compared with CPB, mainly because of lower in-hospital mortality (24,26), while others report no difference in survival but reduction in postoperative complications (27).

ECCO$_2$R

ECCO$_2$R is an EMCS modality that partially clears carbon dioxide from circulation.

It is indicated in isolated hypercapnia, especially in in patients presented hypercapnic failure of chronic obstructive pulmonary disease or exacerbations in fibrosis and cystic fibrosis patients (5,10,28).

It does not represent a helpful tool in intraoperative cardiorespiratory support.

Novalung

Novalung (Novalung GmbH, Hechingen, Germany) is a pumpless device that consists of a membrane oxygenator in which the flow will depend on the patient's cardiac output. It can be used by peripheral venovenous cannulation or after central cannulation. However, due to the lack of cardiocirculatory support it is not helpful in the intraoperative scenario.

It represents a good tool to successfully bridge patients to lung transplantation, especially in the end-stage pulmonary artery hypertension scenario (5,28).

Conclusions

Although rarely used, EMCS techniques should be part of every general thoracic surgeon armamentarium and should be brought to mind in complex cases or in emergency settings. VV-ECMO remains the most widely used technique, although VA-ECMO can have an important role in cases of need for cardiocirculatory support.

These techniques should be used in specific settings and concentrated in high volume and specialized centers in order to achieve the best possible outcomes in this particularly challenging patient. Every thoracic surgeon should have knowledge of these techniques in order not to deny surgical treatment in those patients that may benefit from it.

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