National review of use of extracorporeal membrane oxygenation as respiratory support in thoracic surgery excluding lung transplantation†

Philippe Rinieri*, Christophe Peillon, Jean-Paul Bessou, Benoît Veber, Pierre-Emmanuel Falcoz, Jean Melki and Jean-Marc Baste

INTRODUCTION

Thoracic surgery is based on resection, which is limited by surgical exposure and safety issues, bound to ventilation and access to large vessels. Thanks to selective ventilation, the thoracic surgeon can approach the large vessels in an optimal way. Sometimes, one-lung ventilation is impossible for anatomical reasons (single lung) or insufficient because of respiratory failure (hypoxaemia after lung exclusion). Moreover, mechanical ventilation (jet-ventilation and in-field ventilation) can be difficult in tracheo-bronchial surgery. The thoracic surgeon must anticipate these complex ventilatory situations and guarantee haemostasis. Surgeons and anaesthetists must reach a compromise between patient oxygenation and surgical exposure.

Veno-venous (VV) or veno-arterial (VA) extracorporeal membrane oxygenation (ECMO) allows good oxygenation in addition to removal of CO₂. There is widespread use of ECMO in medical...
The main indication for VV ECMO is medical: severe acute respiratory distress syndrome (ARDS) [1–4]. Intraoperative use of ECMO remains exceptional in thoracic surgery and is often reserved for cardio-thoracic surgery transplantation departments. There are many indications in lung transplantation. A team from Vienna reported its experience of ECMO in lung transplantation [5]. In preoperative settings, ECMO can be a bridge to transplant. Several centres have now replaced conventional cardiopulmonary bypass (CPB) by ECMO for patients with respiratory and/or cardiac failure during transplantation. For severe primary graft failure, ECMO must be set up early on.

ECMO use during conventional thoracic surgical procedure is limited to the description of clinical cases, but without real consensus. In a postoperative setting, ECMO improves survival in patients with post-pneumonectomy ARDS [6]. Some thoracic surgery departments use ECMO in a framework of therapeutic interventions. In complex ventilatory situations, intraoperative ECMO can ensure good haemostasis and good surgical exposure. ECMO can replace or help one-lung ventilation to ensure haemostasis. The objective of this study was to evaluate intraoperative use of ECMO, as respiratory support in thoracic surgery, excluding lung transplantation. We report the results obtained in France for this indication.

MATERIALS AND METHODS

A national survey on the intraoperative use of ECMO as respiratory support in thoracic surgery was carried out. Lung transplantation and lung resection for tumour invading the great vessels and/or the left atrium were excluded, because they concern respiratory and circulatory support (extracorporeal life support).

This was a multicentre retrospective study. We contacted 34 thoracic surgery centres in France with access to ECMO, including university hospitals and private centres, via internet questionnaire. Supplementary material 1 lists the participating centres and correspondents.

All included patients were operated on under ECMO for respiratory reasons. ECMO was organized in pre- or intraoperative settings. The criteria for exclusion were lung transplantation, cancers with vascular and/or cardiac invasion and intraoperative vascular wounds requiring implementation of ECMO.

Between February and April 2012, all participating centres were sent an e-letter and a first e-questionnaire. The aim of this first questionnaire was to list the number of cases in France. Between April and September 2012, all participating centres were sent a second e-questionnaire (Supplementary material 2). It allowed pre-, intra- and postoperative data collection for every patient.

All data were collected and stored anonymously in Excel (Microsoft) with descriptive statistical analysis. Survival analysis was performed by means of the log-rank test (R software): three groups were compared simultaneously. The difference between the survival curves was statistically significant if P-value <5%.

RESULTS

Thirty-four participating centres

All thoracic surgery centres questioned participated in the national survey. In >90% of the participating centres, ECMO was placed by cardiac or cardio-thoracic surgeons. The patients were operated on under ECMO in 17 centres. Only five centres had at least three cases: Clermont-Ferrand, Dijon, Rennes, Rouen and Toulouse. The number and type of ECMO per centre are detailed in Table 1.

Half of the centres had never previously used ECMO as intraoperative respiratory support. For tracheo-bronchial surgery, they mainly used jet-ventilation or in-field ventilation and did not see the interest of using ECMO. Transtracheal oxygenation was used in a single centre.

Indications of extracorporeal membrane oxygenation

Patients were classified into three groups according to ECMO objectives. In 33 patients, ECMO was set up at the beginning of surgery to allow the surgical procedure.

**Table 1:** Number and types of ECMO/centre

<table>
<thead>
<tr>
<th>Centres</th>
<th>VV</th>
<th>VA (peripheral)</th>
<th>VA (central)</th>
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<tr>
<td>Amiens</td>
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<td>Caen</td>
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<td>2</td>
</tr>
<tr>
<td>Clermont-Ferrand</td>
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<td>Dijon</td>
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<td>2</td>
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<tr>
<td>Grenoble</td>
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<td>2</td>
</tr>
<tr>
<td>Lille</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Limoges</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Marseille</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Martinique</td>
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<td>0</td>
<td>1</td>
<td>3</td>
</tr>
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<td>Foch Hospital</td>
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<td>1</td>
</tr>
<tr>
<td>Institut Mutualiste Montsours</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Georges-Pompidou European Hospital</td>
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<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Rennes</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Rouen</td>
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<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Saint-Etienne</td>
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<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Toulouse</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Tours</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>10</td>
<td>6</td>
<td>36</td>
</tr>
</tbody>
</table>

ECMO: extracorporeal membrane oxygenation; VV: veno-venous; VA: veno- arterial.
In Group 1 (28 patients), ECMO replaced lung ventilation: respiratory support was total. In Group 2 (5 patients), ECMO allowed one-lung or two-lung ventilation to ensure haematosis: respiratory support was partial. Only 5 patients in Group 1 had ARDS at the time of operation. In Group 2, all patients had ARDS and/or borderline respiratory function, not allowing lung exclusion.

At the time of operation, 3 patients had received ECMO for several days for ADRS (Group 3): respiratory support was partial. ECMO allowed one-lung ventilation, facilitating performance of 3 lobectomies.

**Patients and operating indications**

Between March 2009 and August 2012, 36 thoracic surgery patients in France had surgery with ECMO for respiratory reasons. Patient inclusion is detailed in a flow chart in Fig. 1. The study included 13 women and 23 men. Mean age was 54 years.

Twenty patients had surgery with VV ECMO and 16 with VA ECMO (10 peripheral and 6 central cannulations). Twenty-seven patients had scheduled surgery.

Nine patients were operated on as a matter of urgency: 2 tracheo-bronchial wounds, 3 haemostasis surgeries (lung sutures, lobectomy and pneumonectomy), 1 post-traumatic tracheal stenosis, 1 broncho-oesophageal fistula, 1 trachea-oesophageal fistula and 1 lung necrosis.

Operating indications were mainly neoplastic (tracheal tumour, bronchial cancer invading the main bronchus or carina and single-lung cancer). Additional indications were infections (aspergilloma, abscess or lung necrosis), trauma (tracheo-bronchial or lung wounds and post-traumatic tracheal stenosis) and iatrogenia (tracheal necrosis after irradiation, tracheal stenosis after intubation, tracheal wound during intubation, carina wound during oesophagectomy or oesophageal prosthesis) (Figs 2 and 3). Operating indications by the type of ECMO are summarized in Table 2.

**Surgical procedures**

Types of surgery were very different and concerned the trachea (plasty, resection-anastomosis), the carina (resection and reconstruction), the left main bronchus (plasty), the lung (pneumonectomy, lobectomy, wedge and haemostasis) or the mediastinum (lymphadenectomy).

ECMO allowed interruption of ventilation in 28 cases (10 tracheae, 11 carinae, 2 main bronchi and 5 single-lung surgeries). Time off ventilation during ECMO was only available in 21 patients. Median duration was 78 min with VV ECMO and 65 min.
with VA ECMO. Maximal duration was 209 min with VV ECMO and 248 min with VA ECMO.

Anticoagulation

A 50- to 100-IU/kg heparin bolus was administered before cannulation. Anticoagulation was monitored by activated cephalin time in a single centre. All other centres used activated clotting time with objectives varying between 160 and 200 s. Heparin bolus was not administered in case of bleeding or preliminary anticoagulation.

Mortality

No patient died during surgery. For methodological reasons, hospital mortality was only studied on Day 30. Thirty-day mortality was 17% (6 deaths).

There were 2 deaths in Group 1. A 58-year-old man had carina necrosis (after radiotherapy) responsible for mediastinitis. Carina reconstruction was performed with aortic allograft. The femoro-femoral VA ECMO was converted into conventional CPB, because of wound to the aorta meaning dissection. The patient was reoperated on Day 1, but he continued to bleed and died under ECMO on Day 1. A 56-year-old woman had tracheal fistula for tumour under VA ECMO (central cannulation). She was weaned off ECMO within 1 day, but she died from unknown cause on Day 27.

There were 2 deaths in Group 2. A 62-year-old man had bronchial fistula (after right pneumonectomy) with ARDS. VV ECMO was implanted and thoracostomy with flap was performed. The patient was reoperated on Day 3, but he continued to bleed and died under ECMO on Day 11. A 66-year-old man had a broncho-arterial fistula (after right upper lobectomy) with ARDS. VV ECMO was implanted and pneumonectomy was performed. The patient died under ECMO from unknown cause on Day 22.

There were 2 deaths in Group 3. A 21-year-old woman was under VV ECMO for ARDS for 3 weeks. She had lobectomy for pulmonary necrosis, but she died from toxic shock on Day 1. A 49-year-old man was under VV ECMO for ARDS for 8 days. He had a lobectomy for pulmonary bleeding. The patient was reoperated on for bleeding on Days 1, 3, 7 and 23, but he died from toxic shock under ECMO on Day 23.

Thirty-day mortality in Groups 1, 2 and 3 was, respectively, 7, 40 and 67%. Survival was compared between groups. Difference in mortality between Groups 1, 2 and 3 was significant (Fig. 4). Conversely, difference in mortality between scheduled and emergency surgery was not significant.

Weaning from extracorporeal membrane oxygenation

In Group 1, 26 patients were weaned from ECMO, including 21 patients within 24 h of operation. One patient was extubated under ECMO, but duration of support was not given. In Group 2, 3 patients were weaned from ECMO (on Days 3, 6 and 15). In Group 3, only 1 patient was weaned from ECMO (at Day 7).

Complications

Six patients were reoperated on for bleeding at the operating site: pleural and/or pericardiac clot removal. Two-thirds of these patients were still under ECMO at the time of operation.

Only 1 patient was operated on for bleeding at the cannulation site. There was a single infection of scarpa. No deep venous thrombosis or ischaemia of limb arose. When peripheral VA ECMO was used, there was a reperfusion cannula for distal limb, except for axillary cannulation.

<table>
<thead>
<tr>
<th>Types of ECMO (cannulation)</th>
<th>VV</th>
<th>VA (peripheral)</th>
<th>VA (central)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trachea</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Carina</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Left main bronchus</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Single lung</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Pulmonary resection</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Thoracic trauma, pneumothorax</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>10</td>
<td>6</td>
<td>36</td>
</tr>
</tbody>
</table>
ECMO conversion was necessary in 2 patients:

One femoro-femoral VA ECMO was converted into femoro-axillary ECMO on Day 2 and then into VV ECMO on Day 3 because of Harlequin syndrome (competition of flow between the hypoxic blood ejected by the left ventricle and that of ECMO). Anterograde reinjection did not compensate for this severe complication, which was responsible for cerebral hypoxia.

One femoro-femoral VA ECMO was converted into conventional CPB with deep hypothermic circulatory arrest, because of a posterior wall of ascending aorta wound due to radiotherapy. Hypothermic arrest has allowed better access to the carina by transecting the aorta, which was easily repaired after.

Change of the type of ECMO was voluntary for 1 patient:

One femoro-axillary VA ECMO was converted into VV ECMO at the end of intervention to allow completely safe endoscopic treatment the following day (bronchial prosthesis after plasty of the left main bronchus) and to avoid placing pressure on the sutures.

DISCUSSION

Mechanical ventilation and alternative technique to extracorporeal membrane oxygenation

Thoracic surgery frequently requires selective ventilation assisted by right or left, double lumen tubes. Intraoperative hypoxaemia (SaO2 <92%) can be controlled with: FiO2 = 1, expiratory positive pressure, alveolar recruitment, continuous positive airway pressure or mini-ventilation of the excluded lung, clamping of the lung artery of the excluded lung, compression of the excluded lung and side decubitus [7]. These techniques improve oxygenation, but are sometimes responsible for bad surgical exposure.

Selective ventilation is sometimes impossible or very difficult during tracheo-bronchial surgery especially when the left main bronchus is involved. Ventilation can be achieved by a high-frequency jet-ventilation catheter, by a fine probe of 5–6 mm crossing through the anastomosis or by a sterile probe inserted by the surgeon into the distal trachea. Complications of jet-ventilation are lung barotrauma and ventilation problems (obese patients or patients with chronic obstructive pulmonary disease and not always available in a thoracic department) [8].

Endotracheal oxygenation (high oxygen flow through a small probe without tidal volume) is a simple technique for oxygenation with no ventilation producing hypercapnia. Hypercapnic acidosis can be badly tolerated. Furthermore, duration of apnoea is limited (30 min at best) [9], which is not convenient for complex tracheobronchial reconstruction.

Conventional ventilatory techniques for single-lung surgery are selective ventilation of one or two lung lobes thanks to a bronchial blocker, jet-ventilation and intermittent ventilation. These techniques decrease surgical exposure and do not allow complex trachea-bronchial reconstruction with various flaps for example.

In case of ventilator or respiratory failure, the thoracic surgeon can operate with a ventilated lung, but surgery should be short and/or easy (talc, biopsy and wedges).

Extracorporeal membrane oxygenation, alternative to conventional cardiopulmonary bypass?

Initially, conventional CPB was used for intraoperative respiratory support. The Marie-Lannelongue team reported several cases of resection with conventional CPB in locally advanced cancers (T4) [10]. Lung resection for tumour invading the great vessels and/or the left atrium needs respiratory and circulatory support, with a venous reservoir. In case of major vessel injury or severe bleeding, conventional CPB with a venous reservoir allows safer cardiopulmonary support. Conventional CPB remains essential when opening the cardiac cavities and during surgery of the aortic arch or the lung artery trunk.

The first intraoperative use of ECMO as total respiratory support was in 1996 [11], while in France, the first case was described in 2009. There are many advantages to ECMO compared with conventional CPB. Less anticoagulation is necessary, thus a decreasing risk of haemorrhage. In addition, ECMO offers better biocompatibility; inflammatory syndrome is of lesser importance [12]. In carcinological surgery, collecting blood during tumoral dissection could be responsible for tumoral scattering.

Extracorporeal membrane oxygenation for total respiratory support

In our series, ECMO replaced ventilation in 26 cases (Group 1): 22 tracheo-bronchial and 4 single-lung surgeries. For several years now, ECMO has replaced ventilation during surgical procedures.

In 1996, Horita performed two resection-reconstructions: carina and sleeve lobectomy, with VV ECMO [11]. Since then, several cases have been described: carinal resection-reconstruction [12, 13], mediastinal tumour resection, due to compression of the trachea [14], single-lung segmentectomy for cancer [15] and tracheo-bronchial plasty for traumatic break [16, 17]. Oey et al. [18] described emphysematous bulla resection in single lung by thoracoscopy under VV ECMO.

Data concerning duration of ventilatory arrest with ECMO are scarce in the literature. Korvenoja et al. [16] reported ventilatory arrest lasting 48 min with VV ECMO. In our series, the maximal duration of apnoea with VV ECMO was >3 h. Ventilation arrest is
possible with VV ECMO, provided that ECMO flow is sufficient for the patient and that there is no recirculation syndrome. The choice between VV ECMO and VA ECMO in replacing ventilation depends not only on the necessity of circulatory support but also on centre practices.

Extracorporeal membrane oxygenation for partial respiratory support

ECMO associated with selective or conventional ventilation allowed good intraoperative haemostasis in Groups 2 and 3. These 8 patients were in ARDS at the time of operation. They were all operated on with VV ECMO. It would have been difficult or impossible to operate on these patients with conventional ventilation techniques. Operating mortality in these two groups was high: operating indications for ARDS patients must be thought through.

Several authors have described the use of VV ECMO in ARDS or respiratory failure. Limited resection of the lung (wedge or segmentectomy) for aspergillosis or lung abscess was performed under one-lung ventilation thanks to ECMO [19, 20].

Tsunezuka et al. [21] reported 3 cases of lung volume reduction surgery for severe pulmonary emphysema. These 3 patients with respiratory failure benefited from femoro-femoral VA ECMO at the beginning of surgery to allow lung exclusion.

Pumpless extracorporeal lung assist device, alternative to extracorporeal membrane oxygenation?

Wiebe et al. [22] reports 10 patients operated on under pumpless extracorporeal lung assist device. Four patients with low ARDS (PaO2/FiO2 between 200 and 300) were operated on as a matter of urgency (tracheal plasties and bubbles resections). The remaining 6 patients were scheduled: 1 tracheal resection—anastomosis and 5 surgeries on unique lung (wedge, decortication—pleurectomy, bronchial plasties and oesophagectomy). A 500- to 1000-lU/kg heparin bolus was administered before cannulation of the femoral vessels. An average flow of 1.58 l/min and pure endotracheal oxygenation allowed apnoea during 1 h. Noradrenalin was increased or introduced in all patients. Several arterial complications were described. Pumpless extracorporeal lung assist device allowed low oxygenation and required good cardiac function. It is not a safe technique, especially in cases of haemodynamic instability. Pumpless extracorporeal lung assist device with endotracheal oxygenation could be an alternative, in cases without arterial or haemodynamic complications.

Advantages of veno-arterial extracorporeal membrane oxygenation

VA ECMO is essential in case of heart failure associated with respiratory failure. It can support the cardiac and respiratory functions, unlike VV ECMO.

We advise to use VA ECMO in femoro-femoral position for emergency cases, because it allows fast cardiorespiratory support. VA ECMO can assist any kind of patient and any kind of clinical situation, but requires a specific perioperative environment as in a cardiac suite. In emergency, it is difficult to assess cardiac function, for instance in complex broncho-oesophageal fistula with septic issues as described previously. A sepsis or a severe hypoxaemia can be responsible for a haemodynamic instability; then, a cardio-respiratory support can be useful.

VA ECMO can be quickly converted into conventional CPB in case of cardiovascular wound. However, complications of VA ECMO can be serious: arterial dissection, acute ischaemia of limb, brain hypoxaemia and arterial stenosis. Particular care must be taken when the heart still ejects and the lungs are not ventilated, as hypoxaemic blood from the left ventricle will enter the coronary and cerebral circulation, leading to myocardial or brain hypoxaemia [23].

Advantages of veno-venous extracorporeal membrane oxygenation

VV ECMO must be envisaged if respiratory support is necessary. In our series, VV ECMO guaranteed haemostasis for several hours, without any lung ventilation. It can thus replace VA ECMO for standard respiratory indications. It allows good oxygenation, unlike CO2 extraction techniques. VV ECMO can be used for elective cases if there is no cardiac failure or cardiac morbidity, for instance carinal resection in cancer. VV ECMO is simpler and can be done in a general and thoracic theatre with no specific monitoring.

Venous cannulation is less invasive than arterial cannulation. VV ECMO avoids the risks of arterial injury and produces less haemodynamic disturbance. Consequences of air or clot embolization from the circuit are less severe.

Furthermore, VV ECMO allows fast correction of pH and improves oxygenation. It enhances haemodynamic and enables better efficiency of inotropic drugs and myocardial oxygenation [24].

The concept of dual-lumen cannula is attractive (single site of cannulation, mobilization of patient, extubated patient and theoretic decrease in the risk of recirculation). It is recommended that cannula position be monitored with cardiac echography.

VV ECMO complications are thromboembolic venous disease, recirculation and superior cava syndrome.

Choice of extracorporeal membrane oxygenation

The choice of ECMO depends on the degree of urgency, necessity of circulatory support as well as surgical methods and surgical environment.

In case of immediate death risk, cannulas are implanted via femoral vessels. In emergency, it is difficult to assess cardiac function, for instance in complex broncho-oesophageal fistula with septic issues as described previously. VA ECMO is essential if circulatory support is necessary. It allows cardiorespiratory support and can be converted into conventional CPB. Dissection is difficult during resection of the carina by sternotomy in patients with history of radiotherapy, and there is a major risk of vascular wounds: VA ECMO is safer.

The site of cannulation also depends on surgical route: central for sternotomy and peripheral for thoracotomy. For carinal resection by sternotomy, surgical exposure requires aorta mobilization and VA ECMO is needed to ensure circulatory support. VV ECMO is enough for carinal resection by thoracotomy.
In cases of tracheal resection–anastomosis, some centres use VA or VV ECMO, the latter being considered less invasive.

**Bleeding complications under extracorporeal membrane oxygenation**

Bleeding is a major complication. In our series, 17% of the patients had revision surgery for bleeding at the operating site, some of whom several times. Two-thirds of patients were still under ECMO at the time of surgical revision. Prolonged duration of ECMO was probably responsible for haemostasis disorders which favoured bleeding.

With heparined circuits, lower heparin doses are required before cannulation and activating clotting time objectives tend to go down, thus decreasing risk of haemorrhage. For some centres, a 20- to 30-IU/kg heparin bolus was administered before venous cannulation. No heparin is administered in cases of haemorrhagic shock or preliminary anticoagulation.

Others considered that if VV ECMO flow was >3 l/min, heparin could be dispensed with for exclusive intraoperative use, but this has never been tested.

**Switching extracorporeal membrane oxygenation**

Several situations such as circulatory failure under VV ECMO or Harlequin’s syndrome under peripheral VA ECMO require change of the type of ECMO as a matter of urgency.

Case in point, a patient can be operated on under VA ECMO for respiratory support and at the end of surgery, switched to VV ECMO. The latter allows protective lung ventilation and avoids placing pressure on sutures in case of mechanical ventilation with high volumes. Furthermore, interventional endoscopy was performed safely in our series.

Intraoperative conversion of VA ECMO into conventional CPB can be useful in cases of vascular wound; a venous reservoir can be connected to the ECMO circuit.

**Critics of the study**

This was a retrospective study and therefore presents selection biases. There were recruitment and non-answer biases, because we used a questionnaire for analysis. Since data collection was performed by individual centres, some data were missing. Since only 36 patients were included, our results warrant confirmation in a larger cohort. There are no details regarding either additional support (inotropic) or weaning protocols. Concerning monitoring of right cardiac function, we do not think it is compulsory to have a Swan Ganz catheter or TEE to use ECMO in thoracic cases especially in elective cases. If there is any doubt of cardiac failure, monitoring of cardiac function by any device could be worthwhile.

VV ECMO can be used as total respiratory support. Duration of ventilatory arrest under VV ECMO seemed very long (sometimes several hours) and was confirmed by anaesthetic data. VV ECMO can be used for elective cases if there is no cardiac failure or cardiac morbidity, for instance carinal resection in cancer.

This national survey shows that tracheo-bronchial surgery and single-lung surgery (for ventilatory arrest) are feasible under ECMO with acceptable morbi-mortality and major advantages in terms of surgical exposure. In Group 1, 30-day mortality (7%) was comparable with data in the literature for this type of surgery [25].

During tracheo-bronchial surgery, mechanical ventilation is difficult, restricting and even dangerous, requiring an experienced team of surgeons and anaesthetists. ECMO allows elimination of probes from the operating field, thus improving surgical exposure and also decreasing risk of pyothorax. ECMO also enables surgery on patients considered inoperable because of ARDS. Proposal for intraoperative use of ECMO as total respiratory support is summarized in Fig. 5.

**CONCLUSION**

ECMO is increasingly widespread in ICUs. Nevertheless, some questions remain unanswered regarding indications. ECMO is still
exceptional and necessitates both technical platforms and dedicated teams, including surgeons, anaesthetists and nurses.

VV or VA ECMO can serve as total respiratory support in complex tracheo-bronchial surgery or single-lung surgery. Choosing between VV and VA circuits depends on the need for circulatory support, and surgical methods and practices. ECMO allows better surgical exposure than mechanical ventilation.

VV ECMO is less invasive and enables total respiratory support without associated ventilation. VV ECMO can be used for elective cases, for instance carinal resection in cancer.

The role of ECMO as partial respiratory support for respiratory failure or ARDS remains more difficult to determine and must be assessed on a case-by-case basis.

The thoracic or cardiothoracic surgeon must master this technology to ensure best patient care. Intraoperative use of ECMO should still be performed in units dedicated to organ support and CPB.

SUPPLEMENTARY MATERIAL
Supplementary material is available at EJCTS online.

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REFERENCES