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ORIGINAL ARTICLE

Extracorporeal membrane oxygenation support for complex tracheo-bronchial procedures[†]

György Lang*, Bahil Ghanim, Konrad Hötzenecker, Thomas Klikovits, Jose Ramon Matilla, Clemens Aigner, Shahrokh Taghavi and Walter Klepetko

Division of Thoracic Surgery, Department of Surgery, Medical University of Vienna, Vienna, Austria

* Corresponding author. Division of Thoracic Surgery, Department of Surgery, Medical University of Vienna, Währinger Gürtel 18-20, A-1090 Vienna, Austria. Tel: +43-1-404005620; fax: +43-1-404005642; e-mail: gyoergy.lang@meduniwien.ac.at (G. Lang).

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Abstract

OBJECTIVES: The published experience with advanced broncho-plastic procedures performed with extracorporeal membrane oxygenation (ECMO) support is very limited. We examined our results to assess the risks and benefits of this approach.

METHODS: We retrospectively analysed all patients with thoracic malignancies who underwent complex tracheo-bronchial reconstruction under ECMO support in our department between 2001 and 2013.

RESULTS: Ten patients (age range 21–81 years, mean 54 ± 11 years) underwent complex tracheo-bronchial reconstructions under veno-arterial ECMO support. In 7 patients, the underlying pathology was non-small-cell lung cancer, in 2 cases carcinoid tumour and in 1 case adenoid cystic carcinoma. ECMO cannulation was central ($n = 7$) or peripheral ($n = 3$). Mean time on bypass was 113 ± 17 min (range 70–135 min). A complete resection (R0) was achieved in 8 patients (80%). There was no perioperative mortality. Patients were discharged from the hospital after 7–52 days (median 11 days). Median time on ICU was 1 day (range 1–36 days). There was no complication related to the use of ECMO in this series. Mean follow-up time was 1694 ± 1385 days (range 12–4338). The 1-, 3- and 5-year Kaplan–Meier survival was 100, 74 and 56%, respectively.

CONCLUSIONS: Based on this experience, we consider veno-arterial ECMO support as a safe and valuable approach for complex airway surgery.

Keywords: ECMO • Lung cancer surgery • Tracheal surgery

INTRODUCTION

Complex tracheo-bronchial resections and/or reconstructions can be very challenging even with the use of sophisticated cross-table ventilation techniques including jet ventilation. Disturbing tubes and lines in the operation field often impair the surgical access and visibility, whereas the jet stream causes spilling of mucosal tumour cell spread. Also, the lack of haemodynamic stability can become a problem, if for better exposure extended retraction manoeuvres' of the heart or the mediastinum are needed. An established alternative to ventilation in such situations is conventional cardiopulmonary bypass (CPB), which provides both gas exchange and haemodynamic stability at the same time. However, CPB also owns several disadvantages such as increased need for blood products due to full anticoagulation of the patients, or the potential danger of tumour cell spilling through the machine suction system [1–7]. In this situation, veno-arterial extracorporeal membrane oxygenation (ECMO) offers an attractive alternative. While providing both oxygenation and circulation support, it avoids full anticoagulation, and the risk of tumour cell dissemination is reduced due to the closed loop extracorporeal circulation. Our basic experience with the use of ECMO derives from lung transplantation, where it has replaced the use of CPB as standard support method during transplantation completely [8]. Based on this, we also used intraoperative ECMO support for selected cases of tracheo-bronchial resections, either due to the complexity of the planned reconstruction, or in situations, where the limited respiratory reserve of the patient prohibited conventional ventilation techniques. In this retrospective study, we summarize our institutional experience with this approach.

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PATIENTS AND METHODS

Demographics

The study was approved by the Institutional Ethics Committee of the Medical University of Vienna. Between 2001 and 2013, 10 patients (age range 21–81 years, mean 54 ± 11 years, male/female 6/4) underwent complex tracheo-bronchial resections under veno-arterial ECMO support. In 7 patients, the underlying

pathology was non-small-cell lung cancer, in 2 cases carcinoid tumour and in 1 case adenoid cystic carcinoma. All surgical procedures were performed under elective conditions. For preoperative evaluation and clinical staging, bronchoscopy and non-invasive diagnostic work-up including computed tomography (CT) scan, bone scintigraphy, magnetic resonance imaging, and positron emission tomography (PET)-CT was used.

The initial staging of the patients was cT4N0 in 7 cases, cT3N0 in 1 case and cT4N2 in 1 other case. Five patients with stage cT4N0 and the patient with cT3N0 underwent surgery without induction therapy, whereas 2 other patients with stage cT4N0 received induction chemotherapy. The patient with stage cT4N2 underwent induction chemo-radiotherapy (Table 1). According to the special biological features of adenoid cystic carcinoma, the TNM staging was not used for Case 7.

Surgical strategy

In all cases with exception of the patient with adenoid cystic carcinoma (Case 7), the goal was to achieve R0 resection. Resection margins in patients after induction therapy were chosen according to the extension of the tumour before induction. All patients underwent *en bloc* mediastinal lymphadenectomy, and resection margins were checked intraoperatively by frozen section.

ECMO settings

For ECMO support, the Medtronic portable bypass system (Medtronic Bio-Console 560, Medtronic, Inc., Minneapolis, MN, USA) with a hollow fibre oxygenator (Medtronic CPMPCB Affinity BPX-80 or Affinity NT, Medtronic, Inc.) with integrated heat exchanger was used. ECMO support was always used in veno-arterial setting in this series. Both peripheral and central accesses were used. For central cannulation of the ascending aorta, a Medtronic DLP 22 Fr curved tip cannula, for the right atrium, a Medtronic MC2X Three-Stage 29/37 Fr venous cannula was used. For peripheral cannulation, surgical exposure of the inguinal vessels was performed. According to the size of vessels, for the arteria a Bio-Medicus Cannula 15–17 Fr, and for the vein a Bio-Medicus Cannula 17–19 Fr set was used (all from Medtronic, Inc.). Both the cannulae and the circuits were heparin coated (Medtronic Carmeda BioActive Surface). Priming solution was 200-ml Ringer's Lactate solution. The flow was set on 50–80% of estimated cardiac output and guided according to haemodynamic and gas exchange demands. A single dose between 3000 and 5000 IU Na–Heparine was administered i.v. immediately before cannulation.

SUMMARY OF RESULTS

Operative characteristics

The access chosen was either posterolateral thoracotomy (3 patients) or anterolateral thoracotomy (7 patients). Mean time of operation was 225 ± 35 min (range 160–320 min). The indication for extracorporeal support was either the complexity of the planned tracheo-bronchial reconstruction ($n = 8$), or limited lung function due to previous lung resection in Case 2 and 8 ($n = 2$). ECMO cannulation was central in 7 cases and peripheral in 3 cases. Mean time on bypass was 113 ± 17 min (range 70–135 min) (Table 2). There was no need for substitution of blood products in the perioperative period.

Mortality/Morbidity

All 10 patients were discharged from the hospital after 7–52 days (median 11,5 days) and returned to normal life. Eight patients were extubated early postoperatively, 2 (Cases 4 and 8) required prolonged weaning over a tracheostomy due to pneumonia, one of them also required additional VA ECMO support for 5 days. Median time on ICU was 1 day (range 1–36 days).

Recurrent nerve palsy was observed in 1 patient and was effectively treated by thyroplasty. Post-vagotomy pylorus stenosis was

Table 1: Patient demographics

Case	Age	Sex	Histology	Localization	Remarks	Initial staging	Induction	Response	Restaging
1	58	M	SCC	Carina		cT4N0	None		
2	57	F	LCC	Carina	Left pneumonectomy 4 years before	cT4N0	None		
3	61	M	SCC	Left main bronch		cT4N0	Chemo	PR	cT4N0
4	57	M	SCC	LUL, PA[a]		cT4N0	Chemo	PR	cT4N0
5	21	F	Carcinoid	Distal trachea, left main bronch	Right descending aorta	cT4N0	None		
6	55	M	SCC	Carina, right main bronch		cT4N2	Chemo + Rad	NC	cT3N0
7	49	F	Adenoid cystic carcinoma	Trachea, carina		n.a.	None		
8	63	M	SCC	RUL	LLL lobectomy 10 years before	cT3N0	None		
9	81	M	SCC	LUL, PA [a]		cT4N0	None		
10	36	F	Carcinoid	Carina, right main bronch and intermediate bronch		cT4N0	None		

SCC: squamous cell carcinoma; LCC: large cell carcinoma; LLL: left lower lobe; LUL: left upper lobe; PA: pulmonary artery; RUL: right upper lobe; PR: partial remission; NC: near complete remission.
[a]Central invasion of the PA close to the arterial carina.

Table 2: Operative characteristics

Case no.	Approach	Type of resection	Reconstruction	Time of operation (min)	Type of cannulation	Site of cannulation	Bypass duration (min)
1	ALT, right	Carina	Y reconstruction (neocarina)	180	Central	RA, AoA	113
2	PLT, right	Carina	Trachea-right main bronch end-to-end	240	Central	RA, AoA	135
3	PLT, right	Carina, left main bronch	Trachea-left main bronch end-to-end, right main bronch-trachea end-to-side	210	Central	RA, AoA	132
4	Hemiclamshell, left	Sleeve pneumonectomy left, left PA (central resection)	Trachea-right main bronch end-to-end	235	Peripheral	Inguinal, right	117
5	ALT, left	Carina	Trachea-right main bronch end-to-end, left main bronch-trachea end-to-side	320	Peripheral	Inguinal, left	127
6	ALT, right	Upper bilobectomy with carinal sleeve	Trachea-left main bronch end-to-end, right lower lobe-left main bronch end-to-side	270	Central	RA, AoA	120
7	ALT, right	Carina and distal trachea	Left main bronch into intermediate bronch end-to-side, trachea-right main bronch end-to-end	235	Central	RA, AoA	132
8	ALT, right	Bronchovascular sleeve RUL		185	Central	RA, AoA	70
9	ALT, left	Bronchovascular sleeve LUL		160	Peripheral	Inguinal, left	85
10	PLT, right	Carina, right main bronch and intermediate bronch	Trachea-left main bronch end-to-end, right main bronch end-to-side into the left main bronch, right upper lobe bronch end-to-side into trachea	215	Central	RA, AoA	102

PLT: posterolateral thoracotomy; ALT: anterolateral thoracotomy; RUL: right upper lobe; PA: pulmonary artery; RA: right atrium; AoA: aorta ascendens; LUL: left upper lobe.

observed early postoperatively in another patient and was successfully treated by gastroscopic botox infiltration (Table 3).

Resectability

A complete resection was achieved in 8 of 9 patients with NSCLC (89%). One patient (Case 2) had negative resection margins at intraoperative frozen section; however, final pathology revealed microscopic tumour involvement at the resection line. In Case 7, the R2 resection was anticipated but accepted by intention in the setting of an adenoid cystic carcinoma with near complete carinal obstruction. The preoperative clinical staging was underestimating the pathological tumour stage in 5 cases (Table 4).

Survival

After a mean follow-up of 16 938 ± 13 849 days (range 12–4338 days), 7 of 10 patients are still alive. One patient died due to distal and local recurrence (skin metastasis and mediastinal lymph node recurrence) 61 months after the operation, which was the patient with R1 resection. Local tumour recurrence in mediastinal nodes was observed in 1 further patient who died 37 months after the surgery. One patient died due to COPD exacerbation 20 months after operation, however without any evidence for residual malignancy. Six patients are still disease-free, and also the patient with adenoid cystic cancer is still alive (Table 4). One-, 3- and 5-year Kaplan–Meier survival is 100, 74 and 56%, respectively (Fig. 1).

DISCUSSION

The challenge in complex tracheo-bronchial resections is always the combined need for both sufficient surgical exposure and adequate control of ventilation. The most widespread technique to maintain intraoperative oxygenation is cross-table ventilation of the distal airways over sterile tubes. This can be replaced or partly combined with high-frequency jet ventilation or high-flow oxygen insufflation over small diameter catheters; however, the latter approach often cannot provide adequate carbon dioxide delivery. The use of CPB is considered rather as a rescue tool in emergency situations in this type of surgery [9].

In contrast, CPB represents an established approach for intraoperative support in local advanced thoracic malignancies. Technical details and results of such operations on CPB have been described in several smaller case series [2, 4–6, 9–13]. However, the indication for extracorporeal support in the majority of these reports consisted of resection of the heart or great vessels in combination with rather simple lung resections such as lobectomies or pneumonectomies.

The published experience with ECMO support for general thoracic procedures is limited, and belongs mainly to the neonatal-paediatric field. Kunisaki *et al.* reported 2 cases of successful intrapartal resection of life-threatening thoracic masses in newborns under preterm delivery conditions, where ECMO support was installed before placental circulation was intercepted (*ex utero* intrapartum treatment (EXIT)-to-ECMO procedure). Resection was performed under ECMO support, intubation and ventilation was started only after removal of the thoracic masses [14]. Several

Table 3: Perioperative mortality and morbidity

Case no.	Extubation (POD)	ICU stay (POD)	Hospital stay (POD)	Survival on POD 30	Complications
1	0	1	7	Alive	
2	0	1	15	Alive	Post-vagotomy syndrome
3	0	1	8	Alive	Recurrent nerve palsy left
4	30	36	42	Alive	Pneumonia, prolonged weaning
5	1	2	10	Alive	None
6	0	1	12	Alive	None
7	0	1	7	Alive	None
8	16	20	52	Alive	Aspiration on POD 2, pneumonia, ECMO support on POD 9–13, prolonged weaning
9	0	1	12	Alive	None
10	0	1	11	Alive	None

POD: postoperative day; ICU: intensive care unit.

Table 4: Outcomes

Case no.	Surgical margins	pTNM	Current status	Survival (months)	Recurrence	Cause of death
1	R0	pT4N0	Alive	72	None	
2	R1	pT4N2	Dead	61	Skin, mediastinal lymph node	Tumour recurrence
3	R0	pT4N2	Alive	111	None	
4	R0	pT3N1	Alive	143	None	
5	R0	pT4N2	Alive	55	None	
6	R0	pTxNx	Dead	37	Mediastinal lymph node	Tumour recurrence
7	R2	n.a.	Alive	18	n.a.	
8	R0	pT1bN0	Alive	24	None	
9	R0	pT3N0	Dead	20	None	COPD exacerbation
10	R0	pT4N1	Alive	1	None	

COPD: chronic obstructive pulmonary disease.

limited series report about critical paediatric airway surgery under veno-arterial ECMO support, for management of different congenital pathologies, both in an emergency and in an elective setting [15–19]. The surgical procedures performed, included slide tracheoplasty, tracheal homograft transplantation, tracheoplasty with costal cartilage graft and other complex tracheo-bronchial reconstructions partly in combination with repair of pulmonary artery sling or patent ductus arteriosus.

From this paediatric experience, several advantages of the ECMO technique became evident. First, the potential of ECMO as a bridge to definitive tracheal surgery in patients with major airway pathologies was demonstrated. Furthermore, the use of ECMO instead of mechanical ventilation resulted in better visualization at the surgical site and obviated the need for endotracheal tubes and aggressive ventilation techniques with all its potential consequences. Finally and probably most important, the use of ECMO allowed to perform complex operative procedures under completely stable conditions.

Based on these experiences, it was a logical step forward to apply intraoperative ECMO support in the adult field as well. There, the published experience mainly derives from Japanese centres. Horita *et al.* [20] reported on two carinal reconstructions performed on peripheral veno-venous ECMO support. Kondo *et al.* [21] performed two left sleeve pneumonectomies over a clamshell incision with central veno-arterial ECMO support. Kodama [22] used a percutaneous veno-arterial ECMO system in 3 cases of oesophageal cancer, where a reconstruction of the carina became necessary.

Our own experience with operations on ECMO mainly derives from the field of lung transplantation, where ECMO has replaced CPB as method of intraoperative support in our department completely [8]. Not infrequently, the intraoperative ECMO support during lung transplantation is extended into the early postoperative period in a prophylactic setting for prevention of reperfusion oedema. Using this approach in this series of 10 cases with tracheo-bronchial reconstructions, the following main points of experience can be summarized.

Clean operative field

In contrast to advanced conventional ventilation techniques, the operative field remains completely clean without disturbing lines or tubes. Moving forward and backward of central airway tubes or repetitive replacement of them into the distal airways require a very good cooperation within the anaesthetist and the surgeon. This can be cumbersome in some situations, resulting in deep desaturation periods, compromising surgical possibilities or endangering an already established anastomosis. All this can also lead to significant prolongation of the operation time. From the surgical point of view, the feature of a completely clean and calm operative field allows for an optimal and precise dissection as well as

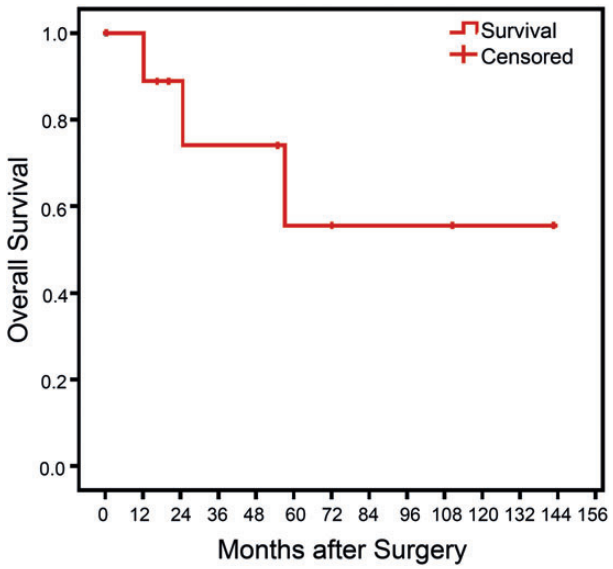

Figure 1: Actuarial survival curve of all 10 patients undergoing tracheo-bronchial resection of thoracic malignancies under ECMO support (time is in months).

suture technique. We consider this as an additional benefit to fulfil the main goal of complete (R0) resection, which is one of the cornerstone principles in oncological surgery.

Haemodynamic stability

The cardiocirculatory function of the patients remain completely stable during the whole operative procedure. Especially in complex tracheo-bronchial reconstructions, the possibility to push the heart aside as much as needed, represent conditions that are not available during the use of any other type of intraoperative ventilation support system except CPB.

Bleeding complications

One consideration for choosing ECMO instead of CPB was the attractive possibility to avoid systemic anticoagulation and in this way to prevent bleeding complications. Since the ECMO system itself is heparin coated, intraoperative anticoagulation was performed by administration of 3000–5000 units of heparin only. In our experience, intraoperative bleeding during dissection did not differ from that observed during conventional surgical procedures. Consequently, none of our patients required reoperation for haemorrhage, which is however a commonly reported complication in oncological lung resections performed on CPB support [2, 4–6].

Tumour cell spread

Another expected benefit of the use of ECMO was the potential to prevent tumour cell spread. Theoretically, especially jet ventilation can facilitate intrathoracic dissemination of defoliating mucosa cells. From the other hand, in contrast to CPB, ECMO consists of a closed circulatory system and no suction into a reservoir is performed, therefore tumour cells as well as other cell debris from the operative field cannot be reintroduced into the vascular system [7].

Acute lung injury

Acute lung injury of the contralateral lung with consecutive pneumonia and adult respiratory distress syndrome (ARDS) is commonly reported after oncological resections performed on CPB [2, 4, 6, 9]. In our series, 2 patients experienced similar morbidity, and needed prolonged weaning over a tracheotomy. In Case 8, due to severe ARDS, an additional VA ECMO support between postoperative days 9 and 14 as a bridge to weaning was needed.

In the series of 7 patients with locally advanced non-small-cell lung cancer operated with CPB, De Perrot *et al.* [9] reports on two carina resections, where they started with cross-table ventilation of the left lung, but according to intraoperative pulmonary oedema emergency CPB became necessary. Whereas they state that this type of surgery must be performed without CPB, they suggest an early start of CPB if pulmonary oedema of the contralateral lung develops. In this context, it is worth to mention that under such circumstances VA ECMO bears the additional potential to prolong this support into the postoperative period, providing optimal recovery conditions of the injured lung. In our 2 cases, the evidence of some pulmonary complication was not detected during the procedure, but only later on in the postoperative period.

One could argue that at least some procedures in this report could have been performed with the use of cross-table or jet ventilation. In fact, the procedures presented here were rather extended resections with the need for complex reconstruction (Cases 1, 3, 5, 6, 7 and 10), so far not comparable with standard sleeve or carina resections, which of course are performed in our department with conventional ventilation techniques. In Case 2, an earlier left pneumonectomy, and in Case 8, a left lower lobe lobectomy precluded conventional contralateral ventilation. In Cases 4 and 9, central exclusion of the main pulmonary trunk was necessary for R0 resection of the left pulmonary artery.

The group of Regensburg reported on the use of Novalung as an alternative to CPB or pump-driven ECMO in complex thoracic surgical procedures. In our opinion, although gas exchange capacity of Novalung may allow for longer apnoeic period required for some trachea-bronchial reconstructions, we consider the lack of additional haemodynamic stability as a substantial disadvantage of this modality [23].

Although peripheral cannulation was used only for left-sided procedures in this series, it could be considered for right-sided procedures as well, especially for cases in which the retraction for exposure could compromise the venous return resulting in severe inflow obstruction to the right atrium.

All patients underwent complete non-invasive staging. Preoperatively, mediastinal node involvement was suspected in only 1 case based on findings in PET-CT, but this was not confirmed with histology neither at initial staging, nor at re-staging after induction therapy. Despite high selection of patients, induction regimen was inhomogeneous due to different referring centres. According to the final histology, mediastinal node involvement was underestimated in 3 cases. However, all these cases showed only microscopic nodular disease. Retrospectively, only one of these patients underwent induction therapy. One other patient presented with typical carcinoid tumour, where the value of induction therapy is at least questionable. However, we would suggest including mediastinoscopy rather routinely into the diagnostic work-up of patients selected for such procedures.

Because this report mainly focuses on the technical aspects of intraoperative use of ECMO, perioperative outcome is of

importance. In this regard, the results are encouraging. Despite the fact that all operations were technically challenging, no mortality was observed. In 2 cases, postoperative pneumonia developed, as already discussed above. Regarding morbidity possibly related to extracorporeal circulation, neither bleeding or thrombo-embolic complications nor air embolism or other technical pitfalls were observed. We consider this mainly according to the fact that the use of ECMO is well established in our unit due to its extensive use in lung transplantation. Therefore, we strongly recommend the described approach only for centres with adequate experience with the use of extracorporeal circulation devices.

It must also be emphasized, that no technical problems occurred from the complex reconstructions performed. We believe that this is in part related to the optimal intraoperative conditions, which allow for a very precise surgical handling.

Long-term results in this rather heterogeneous group of patients with different histology and variable adjuvant therapies are difficult to interpret. R0 resection was attempted in all patients except Case 7. The high rate of complete resection by intention (89%) might have positively contributed to the actuarial 1-, 3- and 5-year Kaplan–Meier survival of 100, 74 and 56%, respectively. However, even the patient with R1 resection (Case 2) survived 61 months. In relation to the mean follow-up of 55 months, the observed 10% incidence of distant metastasis was low, which again is a possible argument for the oncological benefit of the technique.

Although any negative effect of extracorporeal circulation on cancer prognosis was never confirmed, open-heart surgery with CPB is known to cause some transient immunosuppression, as highlighted by increases in several immunoregulatory factors with the possibility to interfere with cancer surveillance or facilitate the spread or the growth of hidden cancer cells [24]. In contrast to that, there is growing evidence that miniaturized extracorporeal circulatory systems, which are increasingly used in cardiac surgery, and have similar features like ECMO, have a significantly lower impact on these immunomodulatory systems [25]. Although this effect is only hypothetical and not yet proved, the low incidence of postoperative pulmonary problems together with the promising long-term outcome in our patients might be due to such a potentially beneficial effect on the immune system.

CONCLUSION

Based on this experience, we consider veno-arterial ECMO support as a safe approach and an alternative to CPB for complex tracheobronchial resections or in situations, where standard resection procedures for any reasons are not manageable by conventional ventilation techniques. This method should be reserved to centres with extensive experience and practice in handling of ECMO systems.

Conflict of interest: none declared.

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APPENDIX. CONFERENCE DISCUSSION

Dr H.J. Ankersmit *(Vienna, Austria)*: It was a Viennese thoracic surgeon, Dr Taghavi, who was the first to introduce ECMO support for primary graft dysfunction after heart transplantation, and that was utilized in 1999 and 2000, and it was quite a revolution because at that time all primary graft dysfunction was supported by LVAD devices. György Lang has shown us data from 2001 onwards on 10 patients with very extended tumours who were supported by ECMO and their results look very nice. That was the historical aspect. Now I have three questions. The first question is about bleeding. What about the tubes you were inserting? What is the anticoagulation management with your patients?

Dr Lang: I think one of the main advantages compared to CPB is that you don't need any full anticoagulation for using ECMO. However, we use a single shot for an average adult of between 3000 and 5000 units. The tubes are all coated, so you don't need any further anticoagulation. I have to remark that in this series we had neither thromboembolic nor bleeding complications.

Dr Ankersmit: And what kind of tubes are you inserting? Are they heparin-bound or heparin-coated?

Dr Lang: Yes. What we use as the standard device is the Medtronic, and ECMO with the so-called Carmeda system. It is a heparin coating system of this company.

Dr Ankersmit: The second question goes basically towards my own research. We know about artificial surfaces, like ECMO or LVADs, and using massive immunosuppression. Do we take precautions with antibiotics in those patients if we support them for a while?

Dr Lang: Yes. For this type of surgery, and this is only a short time of support, we of course use antibiotics, third-generation cephalosporins. But I have to mention that if you use ECMO for a longer period of support, for example, in the bridge setting, then we always also have some antifungal treatment prophylactically.

Dr Ankersmit: And the third question is, why do you use venoarterial ECMO? Why not venovenous ECMO or some ILA devices?

Dr Lang: You are absolutely right. There are some reports, from Japan and also from Germany, using a venovenous or the ILA device. If you have a right thoracotomy, you have a very easy way for central access. Otherwise, if you have to go for the inguinal vessels, I don't think that it is less invasive to use venovenous or ILA access; it is the same from the invasiveness point of view. But on venoarterial ECMO, you have very strong haemodynamic stability, what we very often need for this type of surgery, and this is the main reason why we prefer this type of support.

Dr W. Weder *(Zurich, Switzerland)*: I also have a few comments and questions on this interesting work. There is no doubt that ECMO has changed our management in many ways, and your team was certainly one of the groups who pioneered this, especially in the management of complex lung transplantation. Your argument that ECMO facilitates a very nice operating field, without the endotracheal tube, the noise, and spilling and all this, is an argument which I understand, but, on the other hand, it is also kind of a weak argument, because you have to balance this with the side effects and the cost of ECMO. It is certainly much simpler and easier to use jet ventilation than using the ECMO device. So, to justify it, needs a little bit more than just to say it is easier for the surgeon. When is it justified to use ECMO rather than the jet device? I'm sure you are still using jet ventilation for most of the procedures.

I have another technical question also regarding the previous comment. Are you not monitoring the activated clotting time? Are you just injecting heparin without controlling the activated clotting time?

Dr Lang: Yes. The second question is easier to answer. Theoretically, we have a target value of 160 seconds for ACT, but for -

Dr Weder: 100?

Dr Lang: 160. But, to be honest, in this type of surgery, for two hours of extracorporeal circulation, we don't look at that.

Dr Weder: At all?

Dr Lang: No, not really. You look at that, for example, if you have a complicated lung transplantation and you look for prolongation, and then you will get some information about that, but not for this short period.

Regarding the second question, I fully agree with you. I would avoid that the take-home message for this audience should be to try to perform tracheobronchial resections on ECMO. We also use it only in very selected cases. I agree with you that it is the visibility and it is convenient for the surgeon, but it is the balance between many things. The main cornerstones are the complexity of the procedure and the need for an extended exposure, the haemodynamic stability. If you don't need both of them, then you probably are better to go with traditional approaches, with jet and cross-table ventilation, and there are some special situations, as I told you, when you are unable to perform single-lung ventilation.

Dr Weder: Yes, of course. That is obvious.

Dr Lang: In these cases, for this type of surgery, I am fully convinced it is much better than CPB.

Dr Weder: Yes. I mean there is no doubt.

Dr E. Rendina *(Rome, Italy)*: I have one technical question. I agree with Walter saying that probably the superiority of the operative field is not a justification *per se*. To be honest, when we perform these procedures, occasional procedures, we just intubate the distal bronchus without jet ventilation. I personally don't like jet ventilation very much. I prefer intubation. And then if the patient is reasonably young and without comorbidity from the pulmonary standpoint, you can have long periods of non-ventilatory support, which usually gives you time to place the stitches. That was a comment. My question is, for reconstruction of the carina, the case that you have shown was done through a right posterolateral thoracotomy, right?

Dr Lang: Yes.

Dr Rendina: May I ask you why you have selected this approach instead of median sternotomy, which might have given you better exposure? Of course, it is a case-by-case decision, but do you usually prefer posterolateral thoracotomy in these cases rather than median sternotomy?

Dr Lang: Yes, we prefer that. But I fully agree with you that it is sometimes up to the preference of the surgeon.

Dr Q. Abid *(Stoke-on-Trent, UK)*: My question is basically technical. Can you explain how you establish the ECMO? Do you have any experience when you have a problem with your drainage, because that sometimes can happen with the ECMO machine.

Dr Lang: You mean the venous drainage?

Dr Abid: Yes.

Dr Lang: In a patient for this type of surgery, an oncologic patient fit for surgery, for this type of support you need about 50% of the cardiac output, not more, and this is very easy to reach in each case. If you have central cannulation, we most likely use either a two-stage or a winged cannula, and for peripheral access, a 17-French venous cannula at least, and then you should not have any problems with that.