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Temporary right ventricular support following left ventricle assist device implantation: a comparison of two techniques

Pierre-Emmanuel Noly[a], Matthias Kirsch[a,*], Astrid Quessard[b], Philippe Leger[b], Alain Pavie[a],

Julien Amour[b] and Pascal Leprince[a]

[a] Department of Cardiac and Thoracic Surgery, Cardiology Institute, Pitié Salpêtrière Hospital, University of Paris VI, Paris, France
[b] Department of Cardiac Anesthesia and Reanimation, Cardiology Institute, Pitié Salpêtrière Hospital, University of Paris VI, Paris, France

* Corresponding author. Institut de Cardiologie, Groupe Hospitalier Pitié-Salpêtrière, 47-83 Boulevard de l'Hôpital, 75651 Paris, Cedex 13, France.
   Tel: +33-1-42165601; fax: +33-1-42165639; e-mail: matthias.kirsch@bch.aphp.fr (M. Kirsch).

Abstract

OBJECTIVES: Right ventricular failure (RVF) after implantation of left ventricular assist device (LVAD) is a dramatic complication. We compared retrospectively two techniques of temporary right ventricular support after LVAD (HeartMate II, Thoratec Corp, Pleasonton, CA, USA) implantation.

METHODS: From 1 January 2006 to 31 December 2012, 78 patients [mean age 52 ± 1.34 years; 15 women (19%)] received a HeartMate II at our institution. Among these, 18 patients (23%) suffered postimplant RVF treated by peripheral temporary right ventricular support. Aetiology of heart failure was ischaemic in 12 (67%) and dilated cardiomyopathy in 6 (33%) patients. The preimplant RV risk score averaged 5.1 ± 0.59. Ten patients were treated using a femorofemoral venoarterial extracorporeal life support (ECLS) and 8 patients were treated using extracorporeal membrane oxygenation as a right ventricular assist device (RVAD) established between a femoral vein and the pulmonary artery via a Dacron prosthesis (RVAD).

RESULTS: Duration of RV support was 7.12 ± 5.4 days and 9.57 ± 3.5 days in venoarterial ECLS and vein and the pulmonary artery RVAD groups, respectively ($P = 0.32$). Three patients (17%) died while under RV support (venoarterial ECLS, $n = 2$; and vein and the pulmonary artery RVAD, $n = 1$, $P = 0.58$). In the venoarterial ECLS group, 6 (60%) patients suffered major thromboembolic complications including thrombosis of the ECLS arterial line ($n = 2$), ischaemic stroke ($n = 2$) and thrombosis of the ascending aorta ($n = 2$). No major complication was observed in the vein and the pulmonary artery RVAD group ($P = 0.01$). RV support was successfully weaned in 8 (80%) patients of the venoarterial ECLS group and in 7 (87.5%) of the vein and the pulmonary artery RVAD group ($P = 0.58$). The duration of postimplant intensive care unit stay was not different (respectively, 27.5 ± 18.7 days and 20.0 ± 12.0 days; $P = 0.38$) between both groups.

CONCLUSIONS: Temporary support of the failing RV after LVAD implantation using temporary vein and the pulmonary artery RVAD is a promising therapeutic option. This approach provides adequate LVAD pre- and afterload and is associated with significantly less thromboembolic complications.

Keywords: Right ventricular failure • Extracorporeal membrane oxygenation • Left ventricular assistance device

INTRODUCTION

Right ventricular failure (RVF) is one of the most serious complications following implantation of a left ventricular assist device (LVAD) and is associated with significant postoperative morbidity and mortality [1]. Approximately 15% of recipients of latest generation continuous flow LVADs will experience RVF [2]. Despite significant improvements in medical management, use of temporary RV mechanical support is still required in ~6% of recipients [3].

Several techniques have been described to support the failing RV after LVAD implantation [4–9]. Until recently, we used preferentially peripheral venoarterial extracorporeal life support (venoarterial ECLS) in this indication. Since January 2012, however, we have adopted a simplified technique for temporary RV support using peripheral venopulmonary artery right ventricular support

(vein and the pulmonary artery RVAD) as described by Strauch et al. [4, 10]. The aim of the present study was to evaluate our initial experience with this new technique and to compare it with our previous approach.

PATIENTS AND METHODS

Patients

We performed a retrospective review of all patients receiving a HeartMate II LVAD (Thoratec Corp, Pleasonton, CA, USA) at the Institut of Cardiology at the Pitié Salpêtrière Hospital (Paris, France) from 1 January 2006 to 31 December 2012. We retained only patients who suffered severe postimplant RV failure requiring temporary right-sided mechanical circulatory support.

Thus, among 78 patients who underwent a HeartMate II implantation during the study period, 22 patients (28%) developed RVF requiring right ventricular support. Four patients were excluded from the study because RV support was performed using central (*n* = 3) or a completely percutaneous device (*n* = 1) (Fig. 1). Among the 18 remaining patients, 10 were treated using peripheral venoarterial ECLS and 8 using venopulmonary artery RVAD.

HeartMate II implantation and postoperative management

Implantation and management of HeartMate II LVAD followed previously published guidelines [3, 11]. The rotational speed of the LVAD was set according to haemodynamic status and echocardiographic assessment of the left ventricle. For patients receiving post-implant V-FA ECLS, LVAD rotational speed was maintained at lower levels in order to avoid repeated left ventricular suction events.

Right ventricular failure medical management and indications for right ventricular support

RV support was indicated in: (i) patients who suffered overt RV failure during or immediately after weaning from cardiopulmonary bypass despite maximal medical management according to the ISHLT guidelines [11] and (ii) patients at high risk of postimplant RV failure like patients on ECLS prior to LVAD implantation.

Indeed, due to the difficulty of RV assessment in these patients, they were considered at high risk and received systematic RV support after LVAD implantation.

Peripheral venoarterial extracorporeal life support

The implant procedure of venoarterial femorofemoral ECLS was similar to that used for primary cardiogenic shock and has been described elsewhere [12, 13]. After surgical control of the femoral vessels, an inflow cannula (Edwards 20–24-Fr, or Maquet 25–29-Fr) was inserted into the right atrium through the femoral vein and an outflow cannula (Edwards 16–20-Fr, Maquet 15–21-Fr) was inserted into the common femoral artery. To avoid leg ischaemia, a distal reperfusion catheter was systematically inserted into the superficial femoral artery. The ECLS circuit was fully heparin-coated and comprised a centrifugal pump (Rotaflow RF32 centrifugal pump, Maquet Cardiopulmonary AG, Germany) and a hollow-fibre microporous membrane oxygenator (Quadrox D oxygenator, Maquet Cardiopulmonary AG, Germany) with an integrated heat exchanger. Explantation of the cannula required reopening of the groin incision femoral artery suture under general anaesthesia.

Temporary venopulmonary artery right ventricular support

The technique of implantation of venopulmonary RVAD has been detailed elsewhere [4, 14–16]. The venous inflow cannula (Biomedicus venous cannula sizes 24–26 Medtronic, Inc., MN, USA)
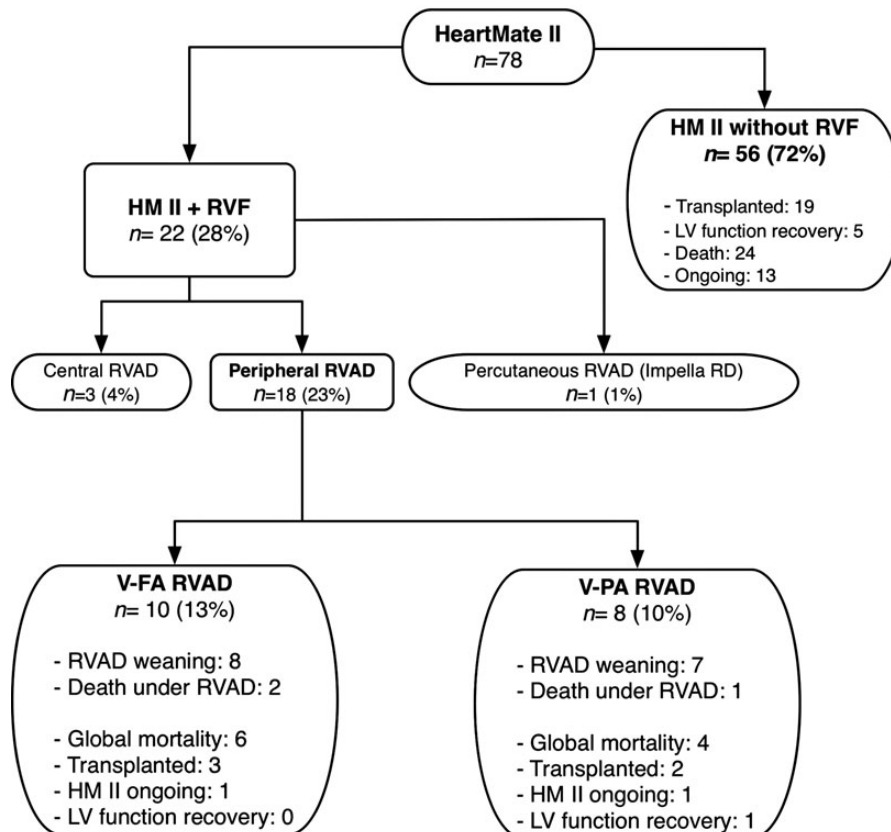
Figure 1: Flowchart. HM II: HeartMate II; RVF: right ventricular failure; RVAD: right ventricular assist device; LV: left ventricular.

was placed percutaneously into the right atrium through a femoral vein using Seldinger's technique. For the outflow cannula, an 8 mm Gelweave Dacron graft (Vascutek Ltd, Scotland, UK) was anastomosed end-to-side to the main pulmonary artery (PA) using a Satinsky side clamp. The outflow arterial cannula (Optisite arterial cannula, Edwards Lifesciences LLC, Irvine, CA, USA) was then inserted into the Dacron graft. The outflow cannula was secured firmly to the chest wall using multiple heavy sutures and connected to a centrifugal pump (Rotaflow RF32 centrifugal pump, Maquet Cardiopulmonary AG, Germany). This set-up was implemented with an oxygenator (Quadrox D oxygenator, Maquet Cardiopulmonary AG, Germany) to assist pulmonary function if necessary.

Explantation of the device was performed in the operating theatre or at bedside in intensive care unit (ICU). After an ultimate weaning trial, the inflow and outflow lines of the RVAD were clamped. The skin exit of the Dacron graft was widely prepared and draped. After local anaesthesia of the cutaneous exit site, gentle traction on the Dacron graft allowed sterile portions from inside the chest to be exposed. The umbilical tapes were cut, and the arterial cannula was removed. The Dacron graft was clamped at the skin level, divided and oversewn using polypropylene sutures and finally allowed to retract into the chest. The skin incision was closely closed using interrupted sutures. The femoral vein was decannulated percutaneoulsy and manual compression secured haemostasis at the venipuncture site.

Criteria for weaning right ventricular support

After surgery, patients were evaluated daily for RV recovery by collecting haemodynamic parameters, routine blood tests and performing weaning trials during which the RVAD flow was reduced to ~1.5 l/min for 15 min. The following criteria were retained for weaning of RV support: (i) no or low levels of inotropic support (dobutamine <5 γ kg^{-1}.min^{-1}; epinephrine or norepinephrine <1 mg^{-1} h^{-1}); (ii) no impairment of renal and liver function with low lactate levels and (iii) stable mean systemic arterial blood pressure around 70 mmHg, with no RV dilatation at echocardiography and no decrease in LVAD flow during weaning trials. Central venous pressure or other right-sided haemodynamic parameters were not considered, since their interpretation under partial RVAD support is awkward.

Anticoagulation protocol. The antithrombotic regimen was the same for all patients. Unfractioned heparin or low-molecular weight-heparin was administered to achieve anti-Xa levels between 0.2 and 0.3 UI/ml. In the absence of clinical bleeding and once the platelet count reached 80 g/l or higher, antiplatelet therapy (acetylsalicylic acid, 160 mg/day) was added.

Data collection. Collected data included patient demographics, baseline haemodynamics, echocardiographic parameters, preimplant clinical condition and laboratory values. The University of Michigan RVF risk score was calculated based on the formula provided by Matthews *et al.* [17]. Scores higher than 5.5 were considered at high risk of postimplant RV failure. In patients under ECLS prior to LVAD implantation, right heart catheterization was not performed. Postoperative clinical, haemodynamic and laboratory data were collected on postoperative days 1, 5 and 10 and just before weaning of RV support. Follow-up was performed in May 2013 and was available for all patients.

Statistical analysis

Continuous data are presented as mean ± standard deviation and compared with Student's *t*-test or two-way analysis of variance, as appropriate. Categorical data are expressed as percentages and compared using a χ^2 or a Fisher's test, as appropriate. A *P*-value of <0.05 was considered statistically significant. Statistical analysis was performed using the SPSS software, version 18 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Baseline characteristics

Baseline patient characteristics are summarized in Table 1. Eleven (61%) patients were on ECLS with or without intra-aortic balloon pump prior to implantation. Patients in the venoarterial ECLS group were more frequently on ventilator at the time of LVAD implantation. Patients in both groups were at high risk of postimplant RV failure but there were no significant differences between both groups.

Procedure related data

Mean duration of cardiopulmonary bypass was 125.5 ± 6.04 min in the vein and the pulmonary artery RVAD group and 126.8 ± 3.9 min in the venoarterial ECLS group (*P* = 0.42). Three patients underwent coronary artery bypass during the same operation (2 in the venoarterial ECLS group). All patients received RV support before leaving the operating theatre.

Outcomes while on left ventricular assist device plus right ventricular support

Mean duration of temporary RV support was not different between the two groups (Table 2). Three patients died while on RV support and mortality while on RV support was not different between the groups. Causes of death are listed in Table 2. Of note, 1 patient in the venoarterial ECLS group died from thrombosis of both the native aortic root and the ECLS arterial line (Fig. 2).

RV support flow and HeartMate II LVAD rotational speed were significantly higher in the venopulmonary artery RVAD group than in the venoarterial-ECLS group (at Day 1, respectively, 4.12 ± 1.2 l/min vs 2.67 ± 0.60 l/min; *P* = 0.005 and 9257 ± 250 rpm vs 8555 ± 384 rpm; *P* = 0.001; Fig. 3). End-organ function tended to improve during support in both groups (Table 3). No heparin-induced thrombopenia was observed and only 1 patient suffered haemolysis 10 days after surgery. Biological profiles after 1, 5 and 10 days were not statistically different between groups (Table 3).

Table 4 summarizes the incidence of various complications while on RV support. Despite a similar anticoagulation profile (Table 2), arterial thromboembolic events were significantly higher in the venoarterial ECLS group. Furthermore, 3 (30%) patients under venoarterial ECLS suffered infection of the femoral cannulation site, which led to femoral artery rupture after weaning in one of them.

All surviving patients were weaned successfully from RV support [venoarterial ECLS, *n* = 8 (80%); venopulmonary artery RVAD, *n* = 7 (87.5%); *P* = 0.58]. Weaning of RVAD was performed under local anaesthesia for 6 patients from the venopulmonary artery RVAD

Table 1: Preoperative characteristics of patients requiring temporary right ventricular support after left ventricular assist device (LVAD) implantation

|	Venoarterial (*n* = 10)	Venopulmonary artery RVAD (*n* = 8)	*P*-value
Age, years	53.1 ± 12.3	50.8 ± 9.9	0.68
Men, *n* (%)	9 (90)	5 (62.5)	
Primary diagnosis, *n* (%)			
Ischaemic cardiomyopathy	8 (80)	4 (50)	0.20
Dilated cardiomyopathy	2 (20)	4 (50)	0.20
Intention to treat, *n* (%)			
Bridge to transplantation	10 (100)	8 (100)	
Destination therapy	0	0	
Medical history, *n* (%)			
Tobacco	7 (70)	4 (50)	0.35
Diabetes	4 (40)	0	0.06
Chronic obstructive pulmonary disease	1 (10)	2 (25)	0.41
High arterial blood pressure	6 (60)	1 (12.5)	0.05
History of heart surgery	0	2 (25)	0.18
Left ventricle function			
Left ventricular ejection fraction (%)	21.8 ± 5.8	13.3 ± 6.8	0.012
Right ventricle function			
RV dilatation on echocardiography, *n* (%)	5 (50)	5 (62.5)	0.48
Central venous pressure (mmHg)	12.10 ± 6.9	-	
Michigan right ventricular risk score	4.7 ± 2.2	5.6 ± 2.9	0.48
Pre LVAD implantation status, *n* (%)			
Mechanical ventilation	6 (60)	1 (12.5)	0.05
No of inotropes	8 (80)	7 (100)	0.56
Intra-aortic balloon pump	7 (70)	4 (50)	0.35
Extracorporeal life support	7 (70)	4 (50)	0.35
Haemofiltration	3 (30)	2 (25)	0.611

Data are expressed as means ± standard deviation.
RVAD: right ventricular assist device.

Table 2: Outcomes after HeartMate II implantation (with or without temporary right ventricular support)

	HM II without RVF (*n* = 56)	HM II + venoarterial ECLS (*n* = 10)	HM II + venopulmonary artery RVAD (*n* = 8)	*P*-value
HM II + temporary RVAD				
Mean duration on RV support (days)	-	7.12 ± 5.4	9.57 ± 3.5	0.32
Mortality, *n* (%)	-	2 (20)	1 (12.5)	0.58
Causes of death	-			
Multi-organ failure	-	1 (10)	1 (10)	0.70
Aortic thrombosis + multi-organ failure	-	1 (10)	0	0.55
Outcomes under isolated LVAD				
Mean duration of LVAD support (days)	320.0 ± 44.46	290.8 ± 180.9	155.25 ± 96.2	0.07
Transplantation, *n* (%)	19 (33.9)	3 (30)	2 (25)	0.61
Weaning of LVAD, *n* (%)	5 (8.92)	0	1 (12.5)	0.44
Switch to TAH, *n* (%)		0	1 (12.5)	
Ongoing LVAD, *n* (%)	13 (23.21)	1 (10)	1 (12.5)	0.70
Mortality under isolated LVAD, *n* (%)	24 (42)	4 (40)	2 (37.5)	0.64
Causes of death under isolated LVAD, *n* (%)				
Suicide	–	1 (10)	0	0.55
Haemorrhagic stroke	–	1 (10)	1 (12.5)	0.55
Ischaemic stroke	–	2 (20)	0	0.55
Tamponade	–	0	1 (12.5)	0.44
Outcomes after transplantation or switch to TAH				
Mortality, *n* (%)	NA	1 (10)	1 (12.5)	
Total mortality at the end of the follow-up	24 (42)	7 (70)	4 (50)	0.48

HM II: HeartMate II; RVAD: right ventricular assist device; RV: right ventricle; LVAD: left ventricular assist device; TAH: total artificial heart; ECLS: extracorporeal life support.
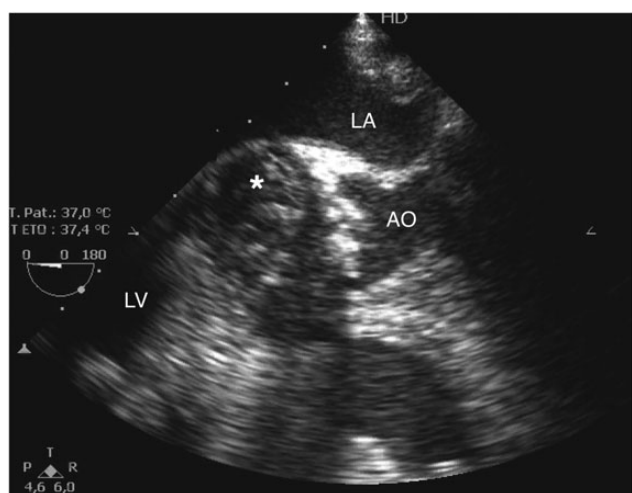
Figure 2: Transoesophageal echocardiographic view of a patient under HeartMate II and temporary venoarterial extracorporeal life support revealing thrombosis of the aortic root (star). LA: left atrium; LV: left ventricle; AO: aorta.
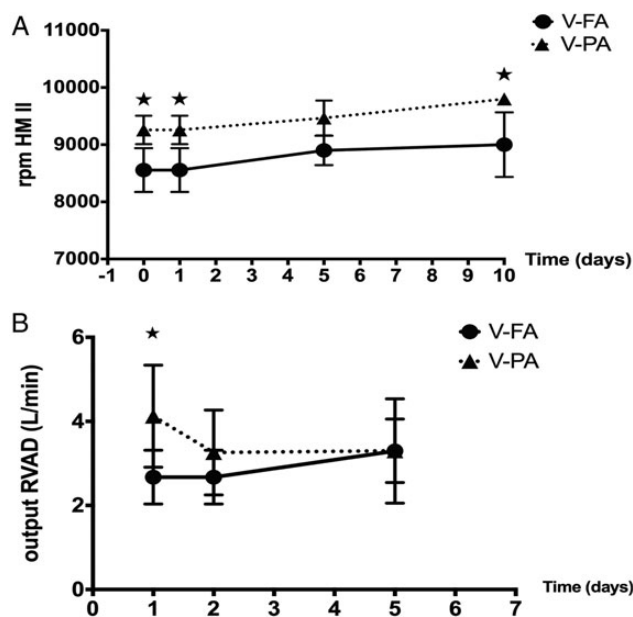
Figure 3: Functional characteristics of left ventricular assist device and temporary right ventricular support. (**A**) Rotation speed of HeartMate II (rpm); (**B**) output of right ventricular support (l/min). (asterisk indicates $P < 0.05$). V-FA: venoarterial ECLS; V-PA: venopulmonary artery.

group but required general anaesthesia for all patient of the venoarterial ECLS group. RV support output immediately prior to explantation was 1.3 ± 0.12 l/min and 1.77 ± 0.25 l/min in the venoarterial ECLS group and the venopulmonary artery RVAD group ($P = 0.20$).

Outcomes after right ventricular support weaning

Mean duration of LVAD support was not significantly different in the two groups (Table 2). Among the 15 patients who could be weaned from RV support, 1 (7%) could be weaned from LVAD, 5 (33.3%) underwent heart transplantation, 6 (40%) died while on isolated LVAD and 1 (7%) required a switch to Syncardia TAH because of late RV failure and pump thrombosis. Finally, 2 (13%) patients were still ongoing at the time of the study. The causes of death during isolated LVAD support are listed in Table 2. Long-term survival was 30% in the venoarterial ECLS group and 50% in the venopulmonary artery RVAD group ($P = 0.48$).

DISCUSSION

Our results suggest that both venoarterial ECLS and venopulmonary artery RVAD are acceptable strategies for managing RVF after HM II implantation. However, although overall mortality was similar with both techniques, we found a significantly lower incidence of major complications in patients who underwent venopulmonary artery RVAD support.

The proportion of LVAD recipients requiring postimplant RV support was slightly higher in our study than in other published reports. This finding might be explained by the critical preimplant clinical status of our recipients, as indicated by the high values of preimplant Michigan scoring. Furthermore, we used a strategy of systematic RV support in patients who were on ECLS prior to LVAD implantation. We acknowledge that doing this, we might have used RV support in patients who could have done without. However, as shown by others, early RV support is critical to outcomes in these patients [18] and, considering the difficulties in evaluating RV function in patients under ECLS, we opted for a preventive strategy. Overall, we observed a relatively low overall mortality when compared with other publications [10, 19], which is most certainly related to the very early implementation of RV support in this series, while the patients were still in the operating theatre.

Several techniques have been proposed to support the RV after LVAD implantation. The most conventional approach requires open chest cannulation of the right atrium and the PA and uses pulsatile, centrifugal or axial flow to support the right ventricle [20, 21]. This approach allows complete unloading of the RV and provides complete antegrade transpulmonary blood flow with adequate preload for the LVAD. However, its major limitation is that general anaesthesia, mechanical ventilation and reopening of the sternum are necessary to retrieve the device, which exposes the patient to inherent bleeding and infectious complications.

Alternatively, completely percutaneous approaches for isolated RV support have been reported. Takayama *et al.* [22] use a centrifugal pump connected to an inflow cannula placed from the femoral vein into the right atrium and a flexible outflow cannula introduced from the right internal jugular vein into the PA. However, this approach requires fluoroscopy and is technically demanding. Recently, an intracardiac percutaneous micro-axial blood pump has been proposed for isolated RV support (Impella RP Abiomed, Inc., Danvers, MA, USA) but this device still remains investigational.

Some authors have proposed peripheral venoarterial ECLS to assist the failing RV. The major advantage is that ECLS can be implemented and retrieved rapidly at bedside, without opening the chest. Furthermore, it can provide pulmonary support for critically ill patients. On the other hand, peripheral venoarterial ECLS results in significant pulmonary shunting with reduced transpulmonary blood flow and provides non-physiological retrograde aortic blood flow. In patients with LVADs, this translates into reduced pump preload and increased pump afterload, which

Table 3: Biological parameters before HeartMate II implantation, on Day 5 and on Day 10 after HeartMate II implantation

	HM II + venoarterial ECLS (n = 10)			HM II + venopulmonary artery RVAD (n = 8)		
	Day 1	Day 5	Day 10	Day 1	Day 5	Day 10
Renal function						
Creatinine (µmol/l)	174.5 ± 130.9	107.9 ± 64.2	125.0 ± 58.4	134.5 ± 93.7	64.5 ± 28.1	83.8 ± 47.0
BUN (mmol/l)	13.2 ± 7.6	9.0 ± 6.8	10.7 ± 5.2	15.2 ± 11.8	9.0 ± 3.4	9.8 ± 6.9
Liver function						
ALT (UI/l)	155.6 ± 203.7	62.3 ± 47.0	463.5 ± 1200	240.5 ± 50.8	37.7 ± 9.8	50.6 ± 38.3
AST (UI/l)	155.4 ± 242.6	47.7 ± 23.1	2103 ± 5836.6	62.2 ± 63.5	60.6 ± 20.1	63.8 ± 36.9
Bilirubine (mg/l)	21.0 ± 21.4	16.0 ± 13.3	26.0 ± 28.1	23.7 ± 16.4	92.1 ± 87.8	79.0 ± 74.4
Haematology						
White blood cells (g/l)	14.2 ± 4.1	14.6 ± 9.3	18.3 ± 10.9	12.9 ± 8.2	16.2 ± 8.5	18.6 ± 5.4
Haematocrit (%)	28.7 ± 5.3	26.8 ± 2.7	26.5 ± 3.1	27.7 ± 2.6	25.9 ± 4.1	23.9 ± 3.1
Platelets (g/l)	205.5 ± 95.5	194.8 ± 145.0	305.5 ± 175.9	165.8 ± 100.5	92.1 ± 37.6	191.2 ± 109.5
Anti-Xa (U/ml)	-	0.02 ± 0.05	0.1 ± 0.2	-	0.06 ± 0.1	0.07 ± 0.1
aPP ratio	1.3 ± 0,2	1.38 ± 0.5	1.64 ± 0.6	1.2 ± 0.2	1.51 ± 0.3	1.68 ± 0.5
Prothrombine time (%)	67.4 ± 13.4	67 ± 26.7	64.44 ± 23.0	65.5 ± 5.9	70.25 ± 6.8	72.50 ± 6,2
Lactates (mmol/l)	1.7 ± 0.2	1.3 ± 0.7	3.5 ± 5.4	1.9 ± 0.3	1.4 ± 0.4	1.2 ± 0.3

BUN: blood urea nitrogen; ALT: alanine aminotransferase; AST: aspartate aminotransferase; aPP: activated prothombine time.

Table 4: Postoperative complications while on left ventricular assist device and temporary right ventricular (RV) support

	HM II + venoarterial ECLS (n = 10)	HM II + venopulmonary artery RVAD (n = 8)	P-value
Duration of intensive care unit stay (days)	27.5 ± 18.7	20.0 ± 12.0	0.38
Complications (n, %)			
Reoperation for bleeding	5 (50)	3 (38)	0.48
Cerebral haemorrhage	1 (10)	0	0.55
Thromboembolic events	6(60)	0	0.01
Ischaemic stroke	2 (20)	0	0.29
Thrombosis of patient ascending aorta	2 (20)	0	0.29
Thrombosis of RV support arterial cannula	2 (20)	0	0.29
Infection of RV support cannulation site	3 (30)	0	0.14
Haemolysis	0	1 (12.5)	0.55
Multiorgan failure	2 (20)	2 (25)	0.61

might compromise LVAD function. In order to limit competition between LVAD and venoarterial ECLS, usually both the LVAD rotational speed and the venoarterial ECLS flow have to be restrained, as shown in our study. This exposes to thrombotic complications that might occur at various sites including the LVAD itself, the aorta or the arterial line of the ECLS and lead subsequently to embolic stroke.

In our opinion, venopulmonary artery RVAD provides a more physiological solution for RV support as it maintains normal transpulmonary blood flow. Its major limitation is that it has to be implanted open chest. On the other hand, it can be retrieved without general anaesthesia and reopening of the sternum. In contrast to venoarterial ECLS, both the LVAD and venopulmonary artery RVAD could be kept at adequate flows and we observed no thrombotic complications. Furthermore, no RV support related infections were noted. In particular, no single infection of the percutaneous exit site of the Dacron graft was noted. Finally, although no systematic pulmonary perfusion scan was performed, there were no signs of pulmonary embolism related to the residual intrathoracic Dacron graft. Aissaoui *et al.* [10] have recently reported the largest experience in treatment of RVF after LVAD

implantation with this hybrid technique. They showed that it is an acceptable treatment with a 6-month Kaplan–Meier actuarial survival of 50% for these critically ill patients. Thus, temporary venopulmonary artery RVAD might be a useful tool in the strategy of treatment of RVF after continuous LVAD implantation.

Conflict of interest: M. Kirsch is consultant for Thoractec, Inc.

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