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BRIEF REPORT

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Ventricular unloading with a miniature axial flow pump in combination with extracorporeal membrane oxygenation

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Abstract *Objective:* ECMO for acute cardiorespiratory failure is an established therapeutic option. Persistent insufficient unloading of the left ventricle (LV) can compromise recovery of ventricular function. We decided to insert a miniature rotary blood pump (Impella) for decompression of the LV. In contrast to previous experience with this new device, where it was generally used for postcardiotomy heart failure or cardiogenic shock and inserted in the operating room or the catheter laboratory, this is the first report describing the potential of this technology in the intensive care unit, in a patient on ECMO and the value of echocardiography guidance. *Patient:* A 13-year-old boy with a history of congenital heart disease was admitted to the ICU with acute cardio-respiratory failure. *Interventions:* On day 2 venoarterial ECMO was instituted because of worsening cardiorespiratory insufficiency refractory to conventional treatment. On day 5 a percutaneous rotary blood pump was inserted to decompress the LV. *Conclusions:* A percutaneous miniature rotary blood pump can be an alternative to decompress a failing LV in the setting of VA-ECMO. Echocardiography can avoid the use of fluoroscopy and the transport to a catheter laboratory to insert the rotary pump.

Keywords Extracorporeal membrane oxygenation · Ventricular assist device · Rotary blood pump · Echocardiography

Abbreviations *AV:* aortic valve · *ECMO:* extracorporeal membrane oxygenation · *LA:* left atrium · *LV:* left ventricle · *LVOT:* left ventricular outflow tract · *MODS:* multiple organ dysfunction syndrome · *RV:* right ventricle · *TEE:* transesophageal echocardiography · *TTE:* transthoracic echocardiography · *VAD:* ventricular assist device · *VA-ECMO:* veno-arterial ECMO

Introduction

The rotary VAD Impella (Impella CardioSystems AG, Aachen, Germany) is a potent miniaturized pump for unloading the left ventricle (LV). The pump incorporates a rotor driven by an electrical motor and has an inflow cannula. The pump is placed across the aortic valve (AV) into the LV, aspirates blood from the LV-cavity and expels it in the ascending aorta. The first developed pump (Impella Recover) has a diameter of 6.4 mm and provides a continuous blood flow of 4.2–4.6 l/min. The driving console allows the management of the pump speed (9 gradations) and displays the pressure difference between inflow and outflow. The Recover-pump has been used successfully in settings of postcardiotomy heart failure [1, 2] and for patients in cardiogenic shock [3] with or without combination of ECMO. Meanwhile, for introduction via a femoral percutaneous approach a 4 mm Impella LP 2.5 has been developed, allowing 2.4 l/min continuous blood flow (Fig. 1). To our knowledge, this

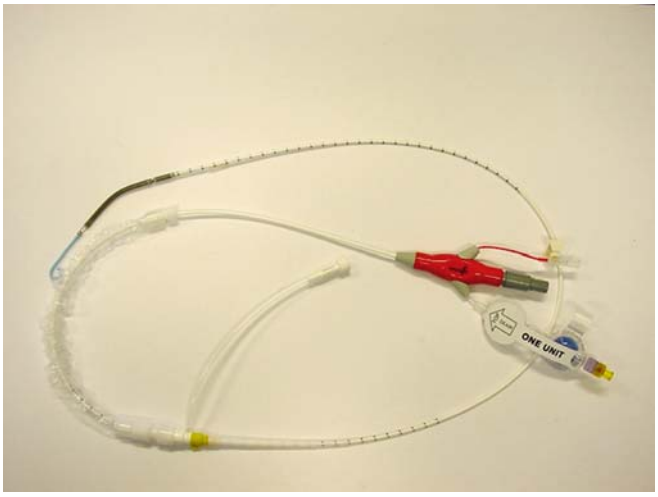

Fig. 1 The Impella LP 2.5 pump

is the first report describing the insertion under transesophageal echocardiography (TEE) guidance of this percutaneous pump at the bedside for unloading the LV in a patient on VA-ECMO.

Case Report

A 13-year-old boy (42 kg, 152 cm) was referred to our institution from a local hospital because of acute respiratory failure. His medical history comprises CATCH 22 syndrome (Di George phenotype, with lymphopenia, T-cell dysfunction, hypocalcemia, limited mental retardation), a truncus arteriosus repair as a neonate followed by aortic root replacement combined with replacement of the right ventricular outflow tract homograft at the age of 5 years, highly reactive airways and recurrent pulmonary infections. Frequent cardiac follow-up at the cardiology clinic showed persistent good myocardial and valvular function.

On admission the child was sedated, intubated and mechanically ventilated. He was poorly perfused and hypoxic on 70% O_2. Chest radiography revealed cardiomegaly and an infiltrate in the right middle and lower lobe. Echocardiography showed a postoperative status after truncus arteriosus repair with minimal aortic regurgitation and a dilated and hypocontractile LV. Arterial blood gas examination upon admission revealed a combined respiratory and metabolic acidosis and hypoxia (pH 7.137, pCO_2 50.1 mmHg, pO_2 86.5 mmHg, SaO_2 91.4%, base deficit of –11.2 mmol/L, lactate 6.1 mmol/L). Blood count revealed a hemoglobin of 12.6 g/dL, platelet count of 113/mm^3, and a leukocyte count of 16.8/mm^3. Further biochemistry results showed an elevated C – reactive protein, renal insufficiency (creatinine 1.7 mg/dL), and elevated liver enzymes and cardiac troponin I. Table 1 gives an overview of laboratory results.

The diagnosis of an acute infection, causing pneumonia and possible myocarditis in an immunodeficient patient was put forward. An extensive microbiological screening, however, remained negative. Therapy consisted of inotropic and vaso-active agents (dobutamine, epinephrine, norepinephrine, and milrinone) under guidance of invasive hemodynamic monitoring with an arterial, central venous and Swan–Ganz catheter; antibiotics, intravenous corticosteroids and immunoglobulines, a lung protective ventilatory management and tight glycemic control (ranges 80–110 mg/dl) with intensive insulin treatment. Despite aggressive support his cardio-respiratory status deteriorated with progressive secondary multiple organ system dysfunction. Repeated echocardiography failed to show any improvement in the cardiac function despite extensive pharmacological support, and it was decided to incorporate mechanical cardiac support.

A femoral VA ECMO was instituted on day 2. VA ECMO was chosen because of the combination of acute respiratory and circulatory failure with the expectancy of recovery. A 21-F venous cannula was placed in the right femoral vein and advanced with the tip in the right atrium. A 19-F arterial cannula was inserted in the right femoral artery through a Dacron graft. Heparin infusion was started after a bolus to maintain activated partial thromboplastin time of 50–80 s. ECMO was initiated at a rate of 120–150 ml/kg per minute. Continuous venovenous hemofiltration was incorporated into the ECMO-circuit to compensate for the renal insufficiency. His overall status gradually improved and over the following hours the inotropic support, and ventilator settings could be firmly diminished.

On day 5 his condition worsened again. He had increased production of foamy and slightly bloody pulmonary secretions, and chest radiography showed worsened cardiomegaly and bilateral infiltrates suggestive of pulmonary edema. TEE revealed a serious dilated and hypocontractile LV with severe mitral valve insufficiency. To unload the LV the decision was made to insert an Impella LP 2.5 system. Surgical insertion at the bedside of a classical LV venting catheter in the left atrium was considered to be very complicated in view of the previous cardiac surgical procedures and anticoagulation. The medical condition of the boy did not allow safe transportation to the catheter laboratory, the Impella device was therefor placed bedside using a percutaneous femoral artery approach, under TEE guidance (procedure is described below). After this intervention the overall hemodynamics, oxygenation, and chest radiography improved, and cardiac troponin levels subsequent declined. Variables monitoring hemolysis are shown in Table 1.

On day 10 the patient developed an acute inflammatory syndrome with new bilateral infiltrates on chest radiography. Combination antibiotic treatment for a multiresis-

Table 1 Laboratory results (*CRP* C-reactive protein, *bili* total bilirubin, *free Hb* free hemoglobin, *cTnI* cardiac troponin I)

	Day 1	Day 2[a]	Day3	Day 4	Day 5[b]	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Normal values
CRP	19.9	28.9	44.3	35.4	27.1	21.8	102.8	165.4	186	225.7	228	< 5-mg/dl
AST	231	7,769	6,094	3,556	1,039	439	243	–	153	215	320	< 38 U/l
ALT	140	3,728	3,883	3,160	2,265	1,690	864	–	423	286	231	< 41 U/l
LDH	1,189	16,920	11,098	7,161	2,721	2,063	2,218	–	2,940	4,636	6,123	240–480 U/l
Bili	1.37	1.32	1.78	2.68	2.61	2.92	4.47	7.77	14.61	25.8	36.21	< 1-mg/dl
Free Hb	< 5	5	8	17	21	< 5	5	7	27	193	136	< 10-mg/dl
Platelet	113	117	156	51	53	62	49	37	45	30	23	150–450
Hb	12.6	10.3	10.5	9.8	8.6	8.8	8.8	9.3	8.2	7.3	9.3	13–16 g/dl
cTnI	6.19	8.90	14.36	48.74	17.98	15.45	12.60	–	–	11.19	–	< 0.13-µg/l

[a] Start ECMO
[b] Start Impella

tant *Pseudomonas aeruginosa* obtained from culture of an endotracheal aspirate was started. Despite VA ECMO and pharmacological support severe metabolic acidosis and hypotension further developed. Respiratory function was further compromised by recurrent serious pulmonary hemorrhages. Despite maximal pharmacological and mechanical support, the child died on day 11 of refractory septic shock.

Autopsy showed an acute bilateral pneumonia with bilateral hemorrhagic syndrome and associated capillaritis. On myocardial microscopic examination the diagnosis of myocarditis could not be confirmed, although presumed at macroscopic inspection. The AV homograft showed calcifications but no endocarditis or traumatic injury caused by the rotary pump. Further cardiac examination confirmed normal findings posttruncus repair.

Impella LP 2.5 device: characteristics and placement

The Impella LP 2.5 support system is a miniaturized rotary blood pump, with a cannula 4.0 mm in diameter. The inflow cannula is prolonged with a pigtail for easier introduction and positioning in the LV (Fig. 1). The pump is placed across the AV, aspirates blood from the LV cavity and expels it into the ascending aorta. The performance depends on the rotary speed of the pump and the physiological afterload. The position of the device is important for optimal function: the pressure signal indicates correct positioning of the pump and is confirmed with echocardiography [4]. Placement is by percutaneous femoral arterial approach using a 13-F sheath. Secondly, through a pigtail-wire, advanced retrograde across the AV into the LV, a 0.014-in. wire is placed in the LV and the pigtail-wire withdrawn. After a test run outside the patient, the pump is advanced over the wire into the LV chamber under fluoroscopic guidance. After withdrawal of the wire, pump rotation is started and gradually increased.

Since this child's condition did not allow safe transportation to the catheter laboratory, the Impella LP 2.5 device was placed bedside under TEE guidance. During and after implantation of the device useful information was provided for correct positioning of the guide wire and the device and for evaluation of ventricular function, as previously reported [2, 4]. After percutaneous placement of a 14-F "peal-away" sheath in the femoral artery, a Judkins right (JR-4) diagnostic coronary catheter was advanced, over a 0.034-in. guide wire until the AV was reached (Fig. 2). By guide wire manipulation the AV was crossed and the diagnostic JR-4 catheter advanced in the LV. A 0.014-in. Trooper support wire (Boston Scientific, Boston, Mass., USA) was advanced through this catheter into the LV. The pump was advanced over this wire, crossed the AV and correct intracardiac position was demonstrated on TEE (Fig. 3). The wire was removed and the pump started. Several follow-up echocardiography examinations showed correct position of the device and good unloading of the LV (Fig. 4).

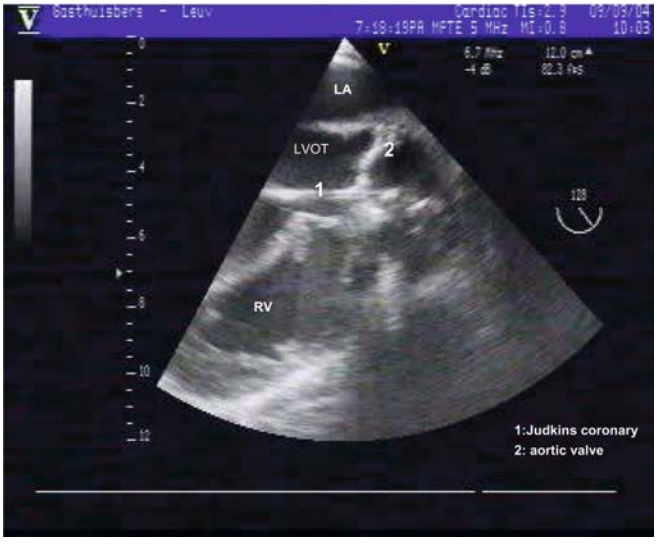

Fig. 2 Judkins diagnostic coronary catheter advanced across the aortic valve into LV

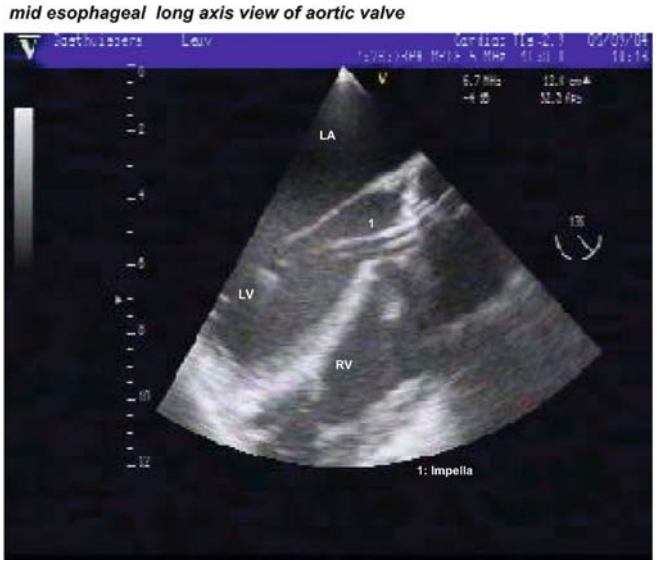

Fig. 3 Impella LP 2.5 intracardiac position mid esophageal long axis view of aortic valve

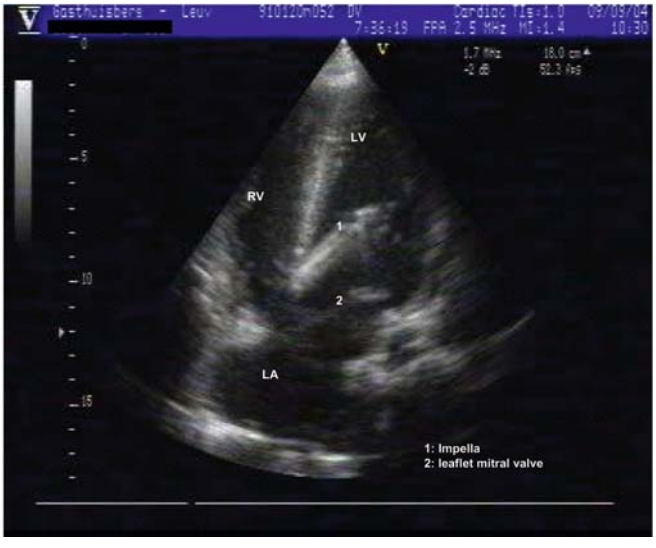

Fig. 4 Transthoracic follow-up echo: position Impella and unloaded LV

Discussion

VA ECMO in the face of severe LV dysfunction often mandates LV decompression (often referred to as venting) because prolonged increased LV wall stress reduces the chances of recovery of ventricular function. This venting can be achieved in several ways: surgically with a catheter placed in the left atrium or percutaneously with a catheter that crosses the atrial septum. This invasive percutaneous technique can be performed in the catheter laboratory or under echocardiography guidance [5]. This transseptal approach requires puncture of the atrial septum and is not without risk. Because of our experience over several years with axial flow pumps in different clinical settings of acute cardiac failure, with or without association of VA ECMO [1, 3], and the possibility in this case of an unsuccessful septostomy after previous closure during truncus arteriosus repair of a patent foramen ovale , we decided to decompress the LV with the Impella LP 2.5. As shown, this miniaturized rotary blood pump can be safely inserted percutaneously at the bedside under TEE guidance, avoiding the risk of transportation of unstable patients. Furthermore, using a percutaneous approach, a (redo) thoracotomy to surgically insert a catheter to unload the LV can be avoided. This case report shows that the Impella LP 2.5 can be a valuable alternative for unloading the LV in patients on VA ECMO.

Close monitoring for hemolysis is advocated during the follow-up of patients treated with the Impella device, as is the case with other VAD. Free hemoglobin, lactate dehydrogenase and total bilirubin were routinely measured for monitoring hemolysis (Table 1). ECMO and VAD can cause hemolysis since red blood cells can be traumatized when passing through the artificial device. The progressive rise in hemolytic parameters in this patient can be explained in multiple ways: prolonged use of the ECMO circuit, association of the axial flow pump, transfusion-related hemolysis, and micro-angiopathic hemolysis as suggested by the autopsy finding of capillaritis, and sepsis and multiple organ system dysfunction.

Conclusion

We report here a valuable alternative for more classical decompression techniques of the LV during VA ECMO, although our patient finally died of sepsis. This technique is less invasive than surgery and can be performed at the bedside under echocardiography guidance. Clinical studies with this new device are ongoing to verify the safety and efficacy in various clinical settings of acute cardiac failure.

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