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MINI-FOCUS ISSUE: HEART FAILURE

ADVANCED

CASE REPORT: CLINICAL CASE

Percutaneous Biventricular Hemodynamic Support Using Biatrial Extracorporeal Membrane Oxygenation

Iyad N. Isseh, MD, Mir B. Basir, DO, Khaldoon Alaswad, MD

ABSTRACT

We describe the use of a fully percutaneous, biatrial extracorporeal membrane oxygenation circuit, to provide biventricular support with left heart unloading by using a single TandemHeart (LivaNova, London, United Kingdom) circuit during high-risk percutaneous coronary intervention. (**Level of Difficulty: Advanced.**) (J Am Coll Cardiol Case Rep 2020;2:1475–9) © 2020 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

In this report, we present the use of fully percutaneous biatrial extracorporeal membrane oxygenation (BA-ECMO) for high-risk percutaneous coronary intervention (HRPCI) in a patient with severe biventricular failure and pulmonary hypertension.

PAST MEDICAL HISTORY

A 62-year-old man had a history of multivessel coronary artery disease that was diagnosed 6 months before admission, ischemic cardiomyopathy, pulmonary hypertension, insulin-dependent diabetes, chronic kidney disease, post-traumatic stress disorder, and severe traumatic kyphotic posture.

LEARNING OBJECTIVES

- To recognize a useful implementation of temporary mechanical circulatory support.
- To understand basic hemodynamics related to BA-ECMO and clinical scenarios where BA-ECMO can be used.

HISTORY OF PRESENTATION

Our patient presented to our emergency department (Henry Ford Hospital, Detroit, Michigan) for decompensated heart failure. His prior coronary angiography films were obtained and reviewed. He was evaluated by a cardiac surgeon, who deemed him a high risk for coronary artery bypass. The patient underwent Swan-Ganz catheter-guided diuresis and medical optimization and was subsequently discharged on guideline-directed medical therapy.

During his outpatient follow-up appointment in the advanced heart failure clinic, he continued to have Canadian Cardiovascular Society class II angina and New York Heart Association functional class III symptoms. He had a heart team discussion with specialists in advanced heart failure, cardiac surgery, and interventional cardiology. The plan was to undergo HRPCI with the goal of providing complete

From the Department of Cardiology, Henry Ford Hospital, Detroit, Michigan. Dr. Basir is a consultant for Abbott Vascular, Abiomed, Cardiovascular System, Chiesi, Procyrion, and Zoll. Dr. Alaswad is a consultant for Boston Scientific and LivaNova. Dr. Isseh has reported that he has no relationships relevant to the contents of this paper to disclose.
The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the *JACC: Case Reports* author instructions page.

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ABBREVIATIONS AND ACRONYMS

BA-ECMO = biatrial extracorporeal membrane oxygenation

ECMO = extracorporeal membrane oxygenation

HRPCI = high-risk percutaneous coronary intervention

LA = left atrial

LV = left ventricular

MCS = mechanical circulatory support

PCI = percutaneous coronary intervention

RA = right atrial

revascularization and subsequent reassessment of cardiac function before consideration of advanced heart failure therapies. In January 2018, our patient was admitted for elective HRPCI.

DIFFERENTIAL DIAGNOSIS

Differential diagnoses included complex coronary artery disease, congestive heart failure in the setting of severe biventricular failure, and pulmonary hypertension. Our patient was planned to undergo elective HRPCI with mechanical circulatory support (MCS) to provide biventricular support with left-sided unloading.

INVESTIGATIONS

Coronary angiography (Videos 1 and 2) revealed the following: no left main coronary artery lesion; ostial chronic total occlusion of the left anterior descending coronary artery; an ostial to proximal critical lesion of the left circumflex artery; and mid-total occlusion of the dominant right coronary artery.

Echocardiography (Videos 3, 4, and 5) detected the following: severe left ventricular (LV) dysfunction with an estimated ejection fraction of 15% to 20%; moderate increase in LV cavity size; moderate decrease in right ventricular systolic function; and severe pulmonary hypertension.

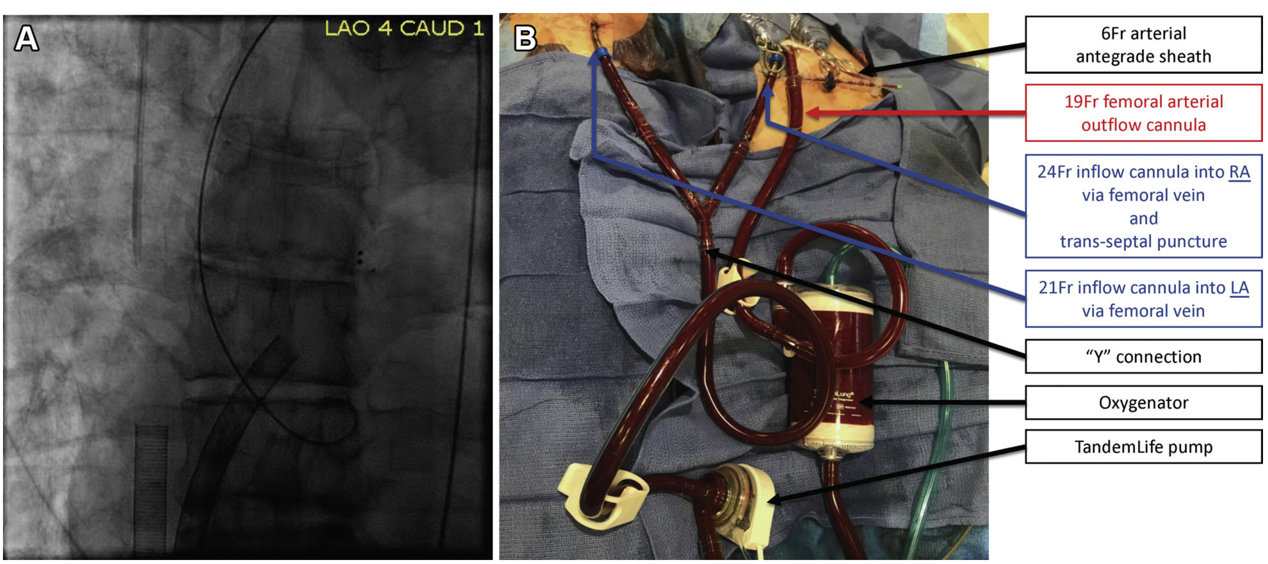
Right-sided cardiac catheterization findings were as follows: mean right atrial (RA) pressure, 9 mm Hg; pulmonary artery systolic, diastolic, and mean pressure: 85 mm Hg, 35 mm Hg, and 52 mm Hg, respectively; mean pulmonary capillary wedge pressure, 30 mm Hg; along with reduced cardiac output and index by thermodilution: 3.2 l/min and 1.58 l/min/m^2; and Fick: 3.47 l/min and 1.71 l/min/m^2, respectively. Pulmonary vascular resistance using Fick cardiac output was 6.9 WU.

MANAGEMENT

Given the underlying biventricular failure and invasive hemodynamics, BA-ECMO support was used (**Figures 1A and 1B**). A 24-F left femoral vein cannula was delivered to the inferior vena cava and right atrium; a 21-F right femoral vein cannula was delivered to the left atrium through transseptal puncture; both venous inflow cannulas were connected in a "Y" fashion through the inlet cannula to the TandemHeart and oxygenator (LivaNova, London, United Kingdom) providing 4 to 5 l/min of flow through a 19-F left femoral arterial outflow cannula; anterograde 6-F access was placed in the left femoral artery to assist with perfusion of the left lower extremity.

The patient underwent successful percutaneous coronary intervention (PCI) of the proximal to middle left circumflex artery and the proximal second obtuse marginal artery with bifurcation stenting;

FIGURE 1 Biatrial Extracorporeal Membrane Oxygenation



(A) Still fluoroscopy of biatrial cannulas. **(B)** "Y" connector and circuit. CAUD = caudal; LA = left atrium; LAO = left anterior oblique; RA = right atrium.

successful chronic total occlusion PCI of the right coronary artery with 3 overlapping drug-eluting stents, the RCA CTO was crossed retrograde via left circumflex epicardial collateral vessels using reverse controlled antegrade and retrograde tracking (rCART). The procedure was performed over an externalized wire. Intravascular ultrasound was used for stent sizing and optimization. Angiographic results are seen in Videos 6 and 7. The left anterior descending artery was scheduled to undergo intervention at a later date.

The patient tolerated the procedure without complications. Results of invasive hemodynamic monitoring remained stable (Table 1). Flow probes attached to the RA and left atrial (LA) drainage cannulas revealed flow to be 2.8 l/min and 2.2 l/min, respectively. On completion of the procedure, the patient was admitted to the cardiac intensive care unit with BA-ECMO support.

Weaning from BA-ECMO occurred the following day. Hemodynamics remained stable, and he was successfully decannulated in the cardiac catheterization laboratory 24 h after the index procedure. He was subsequently discharged home in 72 h in good condition.

FOLLOW-UP

At 6-month follow-up with advanced heart failure and interventional cardiology specialists, he is alive and well. He reported Canadian Cardiovascular Society class I angina and New York Heart Association functional class II symptoms. He has been maintained on appropriate guideline-directed medical therapy and has not required advanced heart failure therapies.

TABLE 1 Right-Sided Heart Catheterization Hemodynamic Parameters Pre- and Post-BA-ECMO

	BA-ECMO		
	Pre (Prior Admission for CHF)	Post (CICU)	Weaning (2-l Flow)
Mean RA (mm Hg)	9	10	12
PA systolic/diastolic/mean (mm Hg)	85/35/52	28/15/19	34/22/26
Mean PCWP (mm Hg)	30	NA	NA
CO/cardiac index (Fick) (l/min)	3.47/1.7	6.2/3.1	5.1/2.5
MAP (mm Hg)	110	100	100
SVR (dynes/s/cm^{-5})	2,328	1,161	1,349

BA-ECMO = biatrial extracorporeal membrane oxygenation; CHF = congestive heart failure; CICU = cardiac intensive care unit; CO = cardiac output; MAP = mean arterial pressure; NA = not applicable; PA = pulmonary artery pressure; PCWP = pulmonary capillary wedge pressure; RA = right atrium pressure; SVR = systemic vascular resistance.

DISCUSSION

Hemodynamic instability during HRPCI can result from repeated transient interruptions of coronary blood flow, leading to myocardial ischemia and negative inotropic effects. Percutaneous MCS may prevent hemodynamic compromise during HRPCI, which may allow for a more complete revascularization (1). Venoarterial extracorporeal membrane oxygenation (ECMO) has increasingly been used in providing biventricular support. However, retrograde aortic flow through the arterial outflow cannula and a supraphysiologic afterload against which an impaired left ventricle is pumping can potentially lead to left ventricular distention. This phenomenon can lead to increased pulmonary capillary wedge pressure, pulmonary artery pressures, myocardial oxygen demand, and pulmonary edema. LV unloading has been proposed to counteract this through multiple strategies

TABLE 2 Characteristics of Different Forms of Percutaneous VA-ECMO

	"Conventional" VA-ECMO	TandemHeart and Oxygenator	BA-ECMO
Pump mechanism	Centrifugal	Centrifugal	Centrifugal
Flow	>4 l/min	>4 l/min	>4 l/min
Cannula size	21-F to 25-F inflow; 15-F to 19-F outflow	21-F inflow; 15-F to 19-F outflow	21-F to 25-F inflow (RA); 21-F inflow (LA); 15-F to 19-F (outflow)
Cannula location	Inflow cannula into the RA through the femoral vein Outflow cannula into the femoral artery	Inflow cannula into LA through femoral vein and transseptal puncture Outflow cannula into the femoral artery	Inflow cannula into LA through femoral vein and transseptal puncture Second inflow cannula into RA through the femoral vein Outflow cannula into femoral artery
Hemodynamics			
RV support	Yes ✓	No ⛔	Yes ✓
Afterload	↑ ⛔	↑ ✓	↑ ✓
LVEDP	↑/↔ ⛔	↓ ✓	↓ ✓
PCWP	↑/↔ ⛔	↓ ✓	↓ ✓

BA-ECMO = biatrial extracorporeal membrane oxygenation; LA = left atrium; LVEDP = left ventricular end diastolic pressure; PCWP = pulmonary capillary wedge pressure; RA = right atrium; RV = right ventricle, right ventricular; VA-ECMO = venous-arterial extracorporeal membrane oxygenation; ↑ = increased; ↔ = no significant change; ↓ = decreased.

FIGURE 2 Cannulation of Different Forms of Percutaneous VA-ECMO

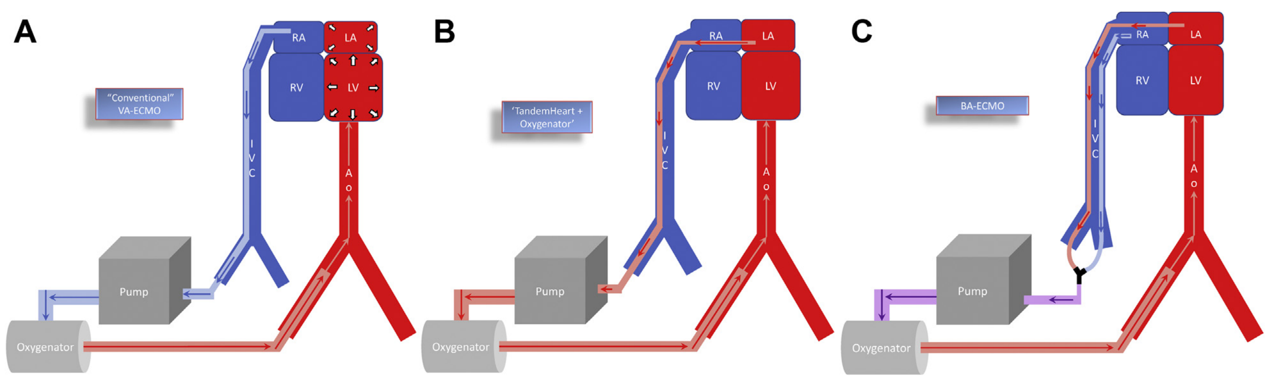


Illustration of the cannulation techniques of different forms of percutaneous venoarterial extracorporeal membrane oxygenation (VA-ECMO). **(A)** "Conventional" venoarterial extracorporeal membrane oxygenation showing a right atrial inflow cannula with deoxygenated blood **(blue)** and a femoral artery outflow cannula **(red).** **(B)** TandemHeart and oxygenator (LivaNova, London, United Kingdom) showing a left atrial inflow cannula with oxygenated blood **(red)** and a femoral artery outflow cannula **(red)**. **(C)** Biatrial extracorporeal membrane oxygenation (BA-ECMO) showing biatrial inflow cannulas with mixed **(purple),** oxygenated **(red),** and deoxygenated **(blue)** blood from left atrial and right atrial inflow cannulas and the "Y" connector **(black).** Ao = aorta; IVC = inferior vena cava; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

(2,3). Percutaneous options for left-sided heart unloading include the use of an Impella device (Abiomed, Danvers, Massachusetts); however, this requires a second large-bore arterial access. Risk of bleeding and other vascular complications can potentially be mitigated when percutaneous left-sided heart unloading occurs without the need for separate arterial access, such as in BA-ECMO. We searched published articles for prior reports of fully percutaneous BA-ECMO (2-5). All prior reports and series describe BA-ECMO in the setting of acute cardiogenic shock. Our patient had BA-ECMO in place for HRPCI and was not in shock at the time of BA-ECMO placement. We have used BA-ECMO in a similar fashion in 2 other patients with severe biventricular failure who were undergoing elective HRPCI. Both patients survived their index procedure and were hemodynamically stable throughout.

There are multiple possible configurations of MCS, each with their own set of advantages and disadvantages. Understanding the hemodynamic effects of common ECMO circuits allows clinicians to use each device in the appropriate clinical context (**Table 2**, **Figures 2A to 2C**). An important hemodynamic concept in BA-ECMO that has not been described previously is the preferential drainage of the right atrium compared with the left atrium. Our first patient had flow measurement of approximately 2.8 l/min and 2.2 l/min from RA and LA drainage cannulas, respectively. Using flow probes intraprocedurally is essential to ensure adequate biventricular unloading. Additionally, our patient had biventricular support with left-sided heart unloading by using a single TandemHeart circuit. The potential advantages of using only 1 pump include resource use and cost reduction. Another common clinical scenario encountered in severe LV dysfunction is the presence of LV thrombus. There are limited, if any, percutaneous options when the need for biventricular support with left-sided heart unloading arises in a patient with LV thrombus. The unique configuration of BA-ECMO can be used in this clinical scenario (3,6). The ability to de-escalate support in a stepwise fashion from biventricular support to LV support only by first removing the RA cannula and leaving the transseptal LA cannula can be helpful when weaning MCS (5,7). Similarly, escalation can occur in a stepwise fashion as well.

CONCLUSIONS

We report a case of fully percutaneous BA-ECMO used for HRPCI in a patient with severe biventricular dysfunction and pulmonary hypertension by using simultaneous drainage of both atria to provide biventricular support with left-sided heart unloading.

ADDRESS FOR CORRESPONDENCE: Dr. Khaldoon Alaswad, Division of Cardiovascular Medicine, Department of Internal Medicine, Henry Ford Hospital, 2799 West Grand Boulevard, Detroit, Michigan 48202. E-mail: kalaswa1@hfhs.org.

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KEY WORDS cardiomyopathy, chronic heart failure, hemodynamics, percutaneous coronary intervention

APPENDIX For supplemental videos, please see the online version of this paper.