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CASE REPORT

INTERMEDIATE

CLINICAL CASE

Percutaneous Closure of the Patent Foramen Ovale on Right Ventricular Mechanical Circulatory Support

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ABSTRACT

Right ventricular infarction can precipitate severe right-to-left shunting and refractory hypoxia from a previously dormant patent foramen ovale. Right ventricle mechanical circulatory support and patent foramen ovale closure can play a crucial role in the treatment of hypoxia and right ventricular recovery. We report a case of successful percutaneous patent foramen ovale closure on right ventricle mechanical circulatory support in a patient with right ventricular shock. (**Level of Difficulty: Intermediate.**) (J Am Coll Cardiol Case Rep 2020;2:300–4) © 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/).

HISTORY

A 60-year-old-male presented to the authors' hospital with 12 h of chest pain and an electrocardiogram showing ST-segment elevation in lead III greater than lead II, aVF, and $V_{1\text{-}3}$, suggestive of inferior wall myocardial infarction (MI) with possible RV infarction (1) (**Figure 1**). Coronary angiography revealed 60% in-stent restenosis in the left anterior descending artery, luminal irregularities in the circumflex artery, and ostial occlusion of the right coronary artery. The right coronary artery, as seen on previous angiograms, was noted to be dominant, with a large RV branch (**Figure 2**). Revascularization was attempted but was unsuccessful. Subsequently, he developed cardiogenic shock requiring inotrope support. Pulmonary artery catheterization revealed an elevated right atrial (RA) pressure at 18 mm Hg, pulmonary capillary wedge pressure (PCWP) of 10 mm Hg, RA to PCWP ratio of 1.8 and a pulmonary artery pulsatility index of 1.1 (on inotrope therapy), suggestive of RV shock. On physical examination, no murmurs were appreciated, and lungs were clear to auscultation. Echocardiography showed a left ventricular ejection fraction of 36% to 40% and a hypokinetic and dilated RV with McConnell's sign (Video 1). He gradually became hypoxic in the semi-Fowler's position which initially improved on lying supine (orthodeoxia-platypnea [O-P]) but continued to worsen thereafter, requiring intubation and mechanical ventilation. Despite a high

> **LEARNING OBJECTIVES**
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> - Right-to-left shunting from a patent foramen ovale is an important cause of refractory hypoxia in patients with ischemic right ventricular dysfunction.
> - Right ventricular shock and right-to-left shunting-mediated hypoxia can be effectively treated with right ventricle mechanical circulatory support.
> - Patent foramen ovale device closure for right-to-left shunting can be safely performed using right ventricle mechanical circulatory support.

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Informed consent was obtained for this case.

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fraction of inspired oxygen, hypoxia persisted and further worsened, with an increase in positive end-expiratory pressure. Emergent chest imaging ruled out pulmonary embolism.

MEDICAL HISTORY. Hypertension, diabetes mellitus, anterior wall ST-segment elevation myocardial infarction treated with a drug-eluting stent in the left anterior descending artery, and elective stenting of the right posterior descending artery.

DIFFERENTIAL DIAGNOSIS. Acute respiratory distress syndrome, pulmonary embolism, congestive heart failure, right-to-left shunting (RTLS) across the atrial septal defect/patent foramen ovale (PFO), pneumonia, and atelectasis.

INVESTIGATION. Given evidence of O-P and persistent hypoxia with clear lung fields, intracardiac RTLS was suspected. A bubble study confirmed severe RTLS from a PFO (Video 2). Given RV shock and RTLS, various modalities of RV mechanical circulatory support (RV-MCS) were assessed and the Heart team opted for a modified Extracorporeal membrane oxygenation (ECMO) circuit with RA-to-pulmonary artery (PA) configuration. A transesophageal echocardiogram (TEE) later showed a large PFO with atypical features such as a long tunnel, large size, and anterior location (**Figure 3**, Video 3). Despite hemodynamic optimization, use of nitric oxide to reduce PA afterload and an initial watchful waiting strategy, the patient could not be weaned from RV-MCS due to recurrence of RTLS and hypoxia at lower levels of circulatory support (**Figures 4A to 4C**, Videos 4A and 4B).

MANAGEMENT. To definitively address the RTLS, percutaneous PFO closure while on RV MCS was chosen. Before PFO closure, the RA cannula was pulled into the inferior vena cava to minimize interaction with the closure device. A 30-mm Amplatzer cribriform occluder (St. Jude Medical-Abbott Vascular, Chicago, Illinois) was deployed (**Figure 5**). After the device was placed, a TEE showed no bubbles crossing the PFO (**Figure 6**, Video 5). RV support was later switched to an Impella RP (Abiomed, Danvers, Massachusetts) as the need for extracorporeal oxygenation had resolved, and RV recovery was awaited. Subsequently, RV function improved, and the patient was weaned from RV-MCS.

ABBREVIATIONS AND ACRONYMS

O-P = orthodeoxia-platypnea

PFO = patent foramen ovale

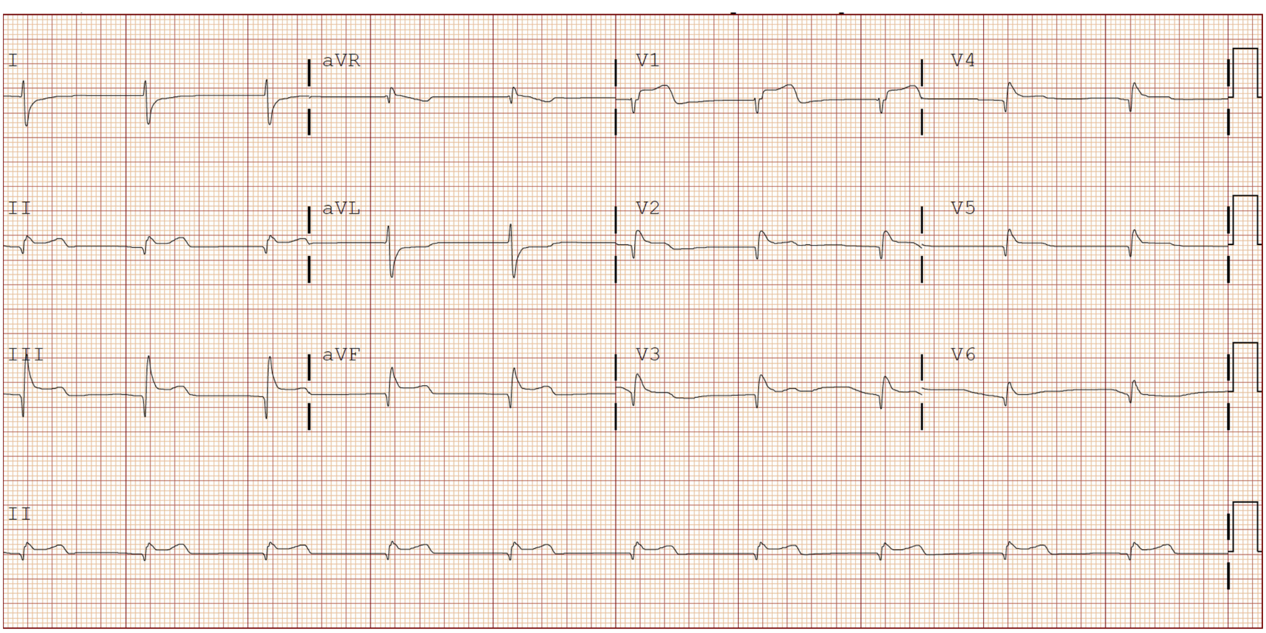
RA = right atrium

RTLS = right-to-left shunting

RV = right ventricle

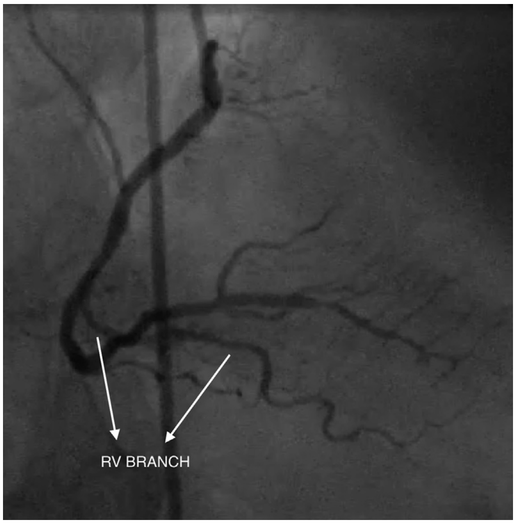
RV-MCS = right ventricle mechanical circulatory support

FIGURE 1 Presenting Electrocardiogram



Presenting electrocardiogram shows ST-segment elevation in lead III greater than lead II, aVF, V_1, V_2, and V_3 suggestive of Inferior wall myocardial infarction with possible right ventricular infarction.

FIGURE 2 **Previous Angiogram**



Previous angiography shows dominant right coronary artery with a large right ventricular (RV) branch.

DISCUSSION

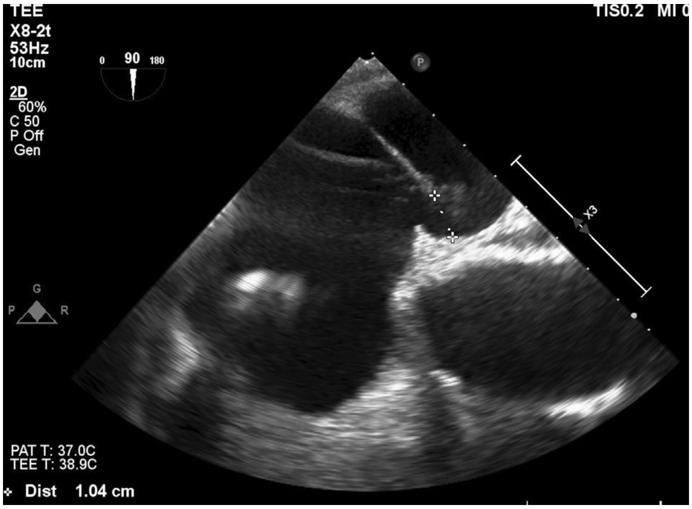
The foramen ovale is a vital interatrial channel that shunts oxygenated blood in the fetal heart. A PFO can be found in 20% to 34% of adults and is clinically silent in most (2). Rarely, PFO can act as a conduit for either transient or continuous RTLS. This case demonstrates the role of RV infarction and shock in activating a previously dormant PFO, leading to severe RTLS and its management.

The RV has several unique structural and physiological properties compared to the left ventricle; properties include a thinner wall, a lower oxygen extraction, a lower chamber pressure, higher oxygen extraction reserve, and a direct perfusion from the RV cavity (3). Despite these favorable perfusion characteristics, occlusion of the RV branch results in RV dysfunction in 40% to 50% of patients (4). RV dysfunction and elevated filling pressures result in an upstream elevation of mean RA pressure which facilitates shunting across an interatrial channel (4). Additionally, other anatomical factors can potentially contribute to RTLS such as the presence of a eustachian valve and positional distortion of the atrial septum in the upright position (5).

Diagnosis of PFO-mediated RTLS can be challenging because it is rare and requires a high degree of suspicion. Clinical clues can facilitate the diagnosis, for example, the presence and worsening of O-P can indicate a gradual increase in shunting and worsening hypoxia with an increase in positive end-expiratory pressure in the presence of clear lung fields could indicate RTLS (6). Definitive diagnosis, however, is determined using echocardiography with agitated saline.

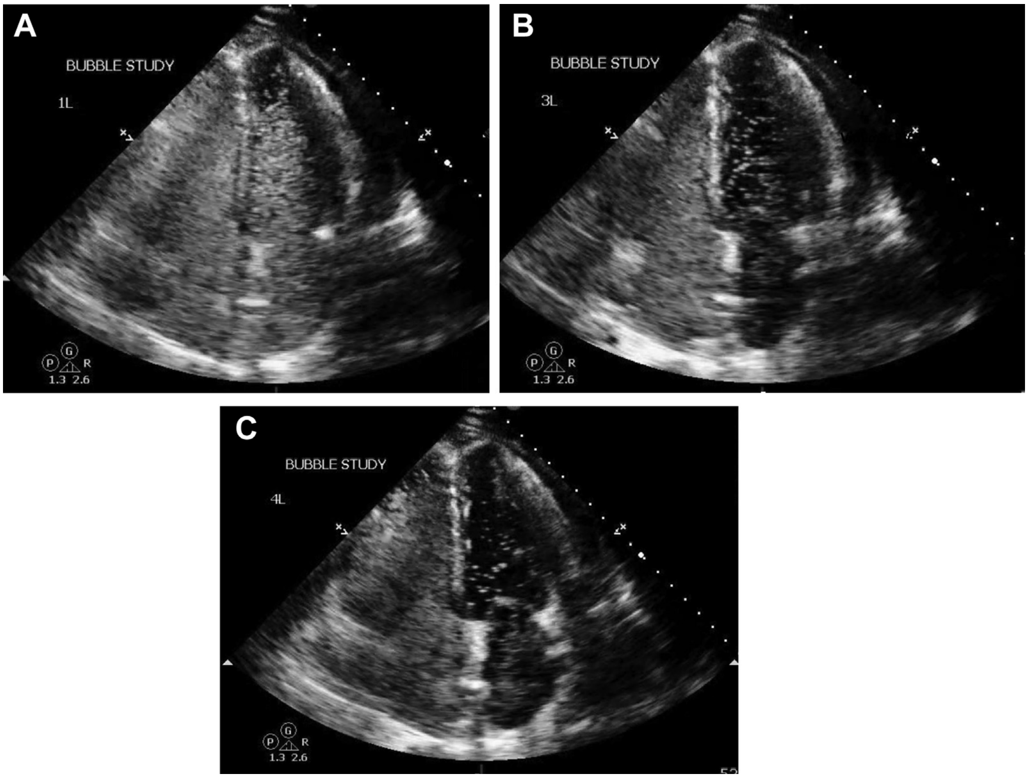
There is a paucity of reports of the management of PFO-mediated RTLS, especially in the setting of RV shock. Acute management includes the use of temporizing measures such as endotracheal intubation and inhaled nitric oxide (7). RA contraction plays a vital role in driving the flow downstream; thus, sinus rhythm and atrial pacing, when necessary, should be encouraged (4). Failure to resolve shunting, especially in the setting of RV shock necessitates the use of RV-MCS. A host of RV-MCS devices are currently available and can broadly be classified as direct RA-PA bypass (Impella RP) and indirect RA-femoral artery bypass (VA-ECMO) (8). Due to refractory hypoxia, a unique MCS strategy using an RA-to-PA ECMO circuit was chosen to provide hemodynamic support and systemic oxygenation. RV recovery plays a crucial role in resolving RTLS. However recovery can be slow, and watchful waiting after medical optimization is a reasonable first-line approach (4). In this regard, RV-MCS can act as a crucial bridge to recovery. Failure to wean from MCS due to recurrent RTLS is a challenging conundrum, and PFO closure could facilitate weaning (9,10).

FIGURE 3 **TEE Shows a Floppy Atrial Septum With a Large PFO**



Transesophageal echocardiogram (TEE) shows a floppy atrial septum with a large patent foramen ovale (PFO) and a 1-cm defect.

FIGURE 4 **RTLS at Various Levels of Circulatory Support**



(A) Severe right-to-left shunting (RTLS) at 1 l of circulatory support., **(B)** Reduced RTLS at 3 l of circulatory support. **(C)** Significantly reduced RTLS at 4 l of circulatory support.

FIGURE 5 **Successful Placement of an Amplatzer Cribriform Occluder**

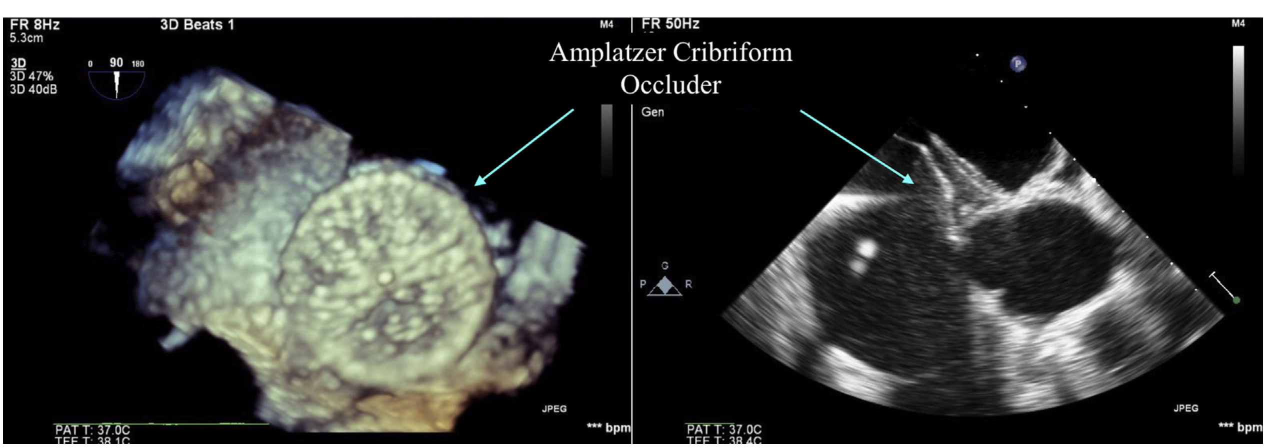
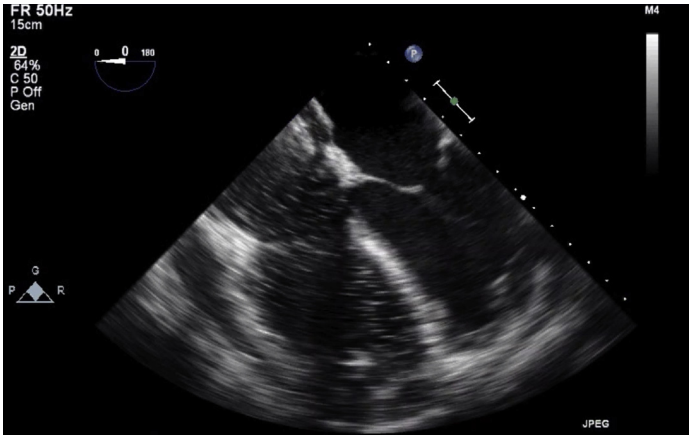


FIGURE 6 No Right-to-Left Shunting Noted on Bubble Study Post-Patent Foramen Ovale Closure



In summary, PFO-mediated RTLS in the setting of RV infarction and shock can be life threatening. RV-MCS can play a vital role in providing hemodynamic support and treating refractory hypoxia. Failure of adequate RV recovery and weaning from MCS could necessitate PFO closure. To the best of the present authors' knowledge, this is the first reported case of safe and effective catheter-based PFO closure performed in percutaneous RV-MCS.

FOLLOW-UP. The patient was discharged home from rehabilitation, continues to attend the cardiology outpatient service, and is currently doing well.

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KEY WORDS acute heart failure, bubble echocardiography, myocardial infarction, occlude, right ventricle

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