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CASE REPORT
Coronary heart disease

A case report of unexpected right-to-left shunt under mechanical support for post-infarction ventricular septal defect: evaluation with haemodynamic simulator

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Background Post-myocardial infarction ventricular septal defect (PIVSD) is a complication of acute myocardial infarction with high mortality. A percutaneous left ventricular assist device, Impella, is currently used in maintaining haemodynamic stability in PIVSD.

Case summary A 65-year-old man was transferred to our hospital for treatment of acute myocardial infarction of the proximal right coronary artery. Percutaneous intervention was performed but haemodynamic instability continued. At 10 days after onset, the patient was diagnosed with PIVSD by echocardiogram. To stabilize haemodynamics, we initiated venoarterial extracorporeal membrane oxygenation (ECMO). Three days after ECMO initiation, pulmonary congestion increased and an echocardiogram revealed closed aortic valve and spontaneous echo contrast at the aortic root. After an Impella 2.5 was inserted for unloading of the left ventricle, the oxygenation level and cardiac function rapidly declined. Unexpectedly, an echocardiogram showed a right-to-left shunt (to-and-fro pattern) via PIVSD. By increasing the ECMO and decreasing Impella flow, the shunt flow changed to left-to-right, and oxygenation level and cardiac function improved. Ten days after ECMO was started, elective surgical repair was successfully performed.

Conclusion ECPELLA (ECMO + Impella) can offset the adverse effects of isolated ECMO support and reduce the PIVSD shunt flow. However, the risk of right-to-left shunt has not been reported, and ECPELLA caused a right-to-left shunt with deoxygenated systemic perfusion in the present case. A simulation study indicated that the right ventricular failure in PIVSD may pose a risk for right-to-left PIVSD shunt under Impella support.

Keywords Post-myocardial infarction ventricular septal defect • Mechanical circulatory support • Extracorporeal membrane oxygenation • Left ventricular assist device • Impella

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Learning points

- Post-myocardial infarction ventricular septal defect (PIVSD) is a fatal complication of acute myocardial infarction, sometimes requiring mechanical support.
- Percutaneous left ventricular assist devices (Impella) usage can be a risk of right-to-left shunt via PIVSD.
- Simulation study indicated that the right ventricular failure in PIVSD may risk a right-to-left PIVSD shunt under Impella support.

Introduction

Post-myocardial infarction ventricular septal defect (PIVSD) is a fatal complication of acute myocardial infarction with high mortality (40–80%).[1,2] To obtain haemodynamic stabilization, mechanical circulatory support devices (MCS) are frequently used as a bridge to assured surgical repair. The intra-aortic balloon is the classical and most commonly used device.[2,3] Recently, extracorporeal membrane oxygenation (ECMO), percutaneous left ventricular assist devices (Impella 2.5, Abiomed, Danvers, MA, USA), and combined usage (ECPELLA) have been reported as more effective options for PIVSD.[4–7]

Generally, a left-to-right shunt occurs through PIVSD, and a right-to-left shunt is rarely observed since surgical repair is performed before right side pressure elevates excessively. Deoxygenated perfusion by right-to-left shunt causes critical damage to the heart and brain. The development of MCS leads to more complicated haemodynamic effects; however, the number of reports is still limited and the haemodynamic effects of different MCS are not fully clarified. In view of these circumstances, Pahuja *et al.*[8] compared the haemodynamic effects of various MCS forms in PIVSD using a simulation model, but the possibility of the risk for right-to-left shunt was not described.

We present a case of unexpected right-to-left shunt under ECPELLA support for PIVSD. Additionally, this unique haemodynamic situation was evaluated with a simulation model to pursue a prevention strategy.

Timeline

Time	Events
10 days before	Sudden chest pain. Inferior ST-elevation myocardial infarction complicated by cardiogenic shock. Percutaneous coronary intervention of the right coronary artery was performed under intra-aortic balloon pump
9–1 days before	Heart failure was uncontrollable by treatment with diuretic and inotropic agents. Echocardiogram revealed ventricular septal defect (VSD)
Transferred to our hospital	Venoarterial extracorporeal membrane oxygenation (ECMO) started
Day 3	Closed aortic valve and spontaneous echo contrast were observed in the aortic root. After Impella (2.5) support initiated, oxygenation level and cardiac function rapidly declined. Echocardiogram revealed right-to-left shunt via VSD. Adjustment of ECMO and Impella flow improved the haemodynamic situation
Day 10	Surgical repair was performed

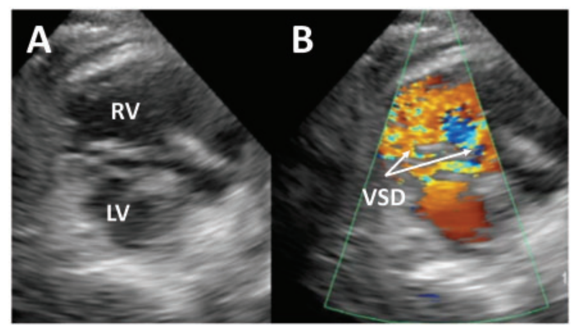


Figure 1 Transthoracic echocardiogram showed left-to-right shunt via ventricular septum defect opening near the base of the heart (A and B). LV, left ventricle; RV, right ventricle; VSD, ventricular septal defect.

Case presentation

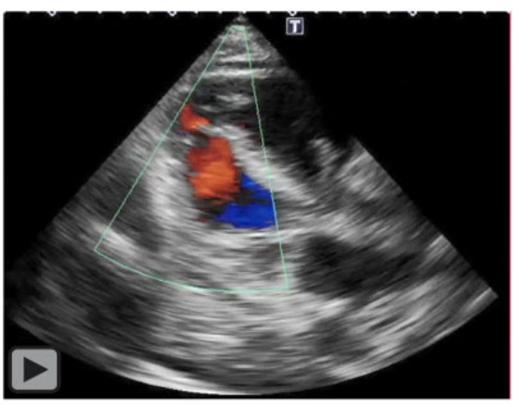
A 65-year-old man was admitted to hospital because of chest pain with an ST-segment elevation of electrocardiogram (II, III, and aVF). His past medical history included hypertension and hyperlipidaemia. Emergency percutaneous intervention for inferior ST-elevation myocardial infarction due to total occlusion of the proximal right coronary artery was performed under intra-aortic balloon pump (IABP) support at 5 h after onset. However, haemodynamic instability continued under noradrenaline administration (0.04 γ). At 10 days after onset, he was diagnosed with inferior PIVSD by echocardiogram and transferred to our hospital. Blood pressure was 74/51 mmHg and heart rate was 81 per minute. Cold sweating and pulmonary rales were observed. Transthoracic echocardiogram showed left-to-right shunt via the ventricular septal defect (VSD) opening near the base of the heart (2.5 cm) (*Figure 1A and B* and *Video 1*). Diastolic and systolic left ventricular dimension was 46 (normal range; 40–56) and 33 (normal range; 20–38) mm. The right ventricular function declined and left ventricular ejection fraction was 50% (normal range; >50%). Systolic pulmonary artery pressure was 50 mmHg (normal range; 15–30 mmHg). To stabilize haemodynamics, we initiated venoarterial

ECMO. Aspirin (100 mg) and heparin (10 000 U) per day were administered. Three days after ECMO initiation, pulmonary congestion worsened and an echocardiogram revealed a closed aortic valve and spontaneous echo contrast at the aortic root. After an Impella 2.5 was inserted for unloading of the left ventricle (LV), oxygenation level and cardiac function rapidly declined. An echocardiogram showed an unexpected right-to-left shunt (to-and-fro pattern) via VSD (*Figure 2A and B* and *Video 2*). By increasing ECMO and decreasing Impella flow, the shunt flow changed to left-to-right, and oxygenation level and cardiac function improved (*Figure 2C*). Ten days after the start of ECMO, elective surgical repair was successfully performed. Although postoperative echocardiogram showed no residual shunt, biventricular dysfunction did not recover sufficiently (Supplementary material online, *Figure S1*) and the patient was unfortunately died due to new-onset cerebral infarction at 5 days after operation.

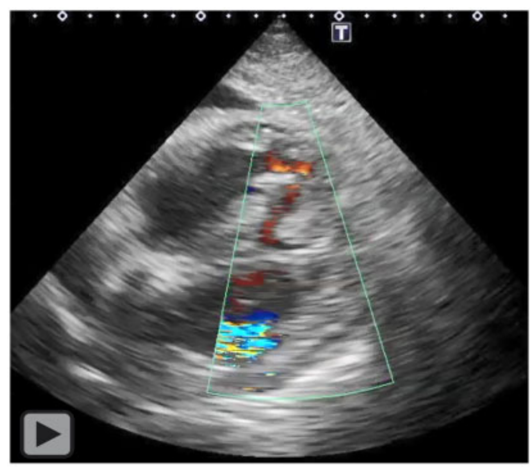
Discussion

Venoarterial ECMO is effective for PIVSD, but is not the ultimate option. Sometimes, decreased arterial pulse pressure, signifying increasingly less aortic valve opening, can increase the risk of pulmonary congestion and aortic root thrombus formation.[8,9] As prevention methods of root thrombosis, usage of inotropic agent or decrease of ECMO flow to re-open the aortic valve and introduction of Impella support were effective. Pahuja *et al*. found through simulation models that ECMO initiation increased flow through the VSD, afterload pressure on the LV, and pulmonary pressures. They also found that ECPELLA offset the adverse effects of isolated ECMO support and reduce the VSD shunt flow.[8] However, the risk of right-to-left shunt was not reported. In the present case, ECPELLA caused a right-to-left shunt with deoxygenated systemic perfusion.

To understand the haemodynamics in our case, we conducted a simulation study. We used a cardiovascular simulator (Supplementary material online, *Figure S2*) based on the electrical circuit to simulate the PIVSD dynamic haemodynamics (see Supplementary material online).[10] Simulation results are illustrated as pressures in systemic and pulmonary circulation, flows of MCS and VSD, and pressure–volume loop. To create a case-specific



Video 1 Transthoracic echocardiogram showing left-to-right shunt.



Video 2 Transthoracic echocardiogram showing unexpected right-to-left shunt.

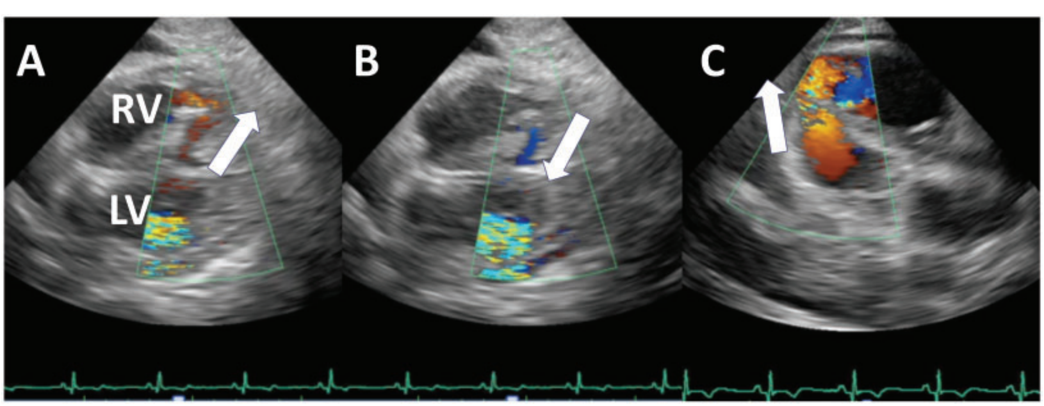


Figure 2 Echocardiogram showed unexpected right-to-left shunt (to-and-fro pattern) via ventricular septal defect (*A* and *B*). By increasing extracorporeal membrane oxygenation and decreasing Impella flow, the shunt flow was changed to left-to-right (*C*). LV, left ventricle; RV, right ventricle.

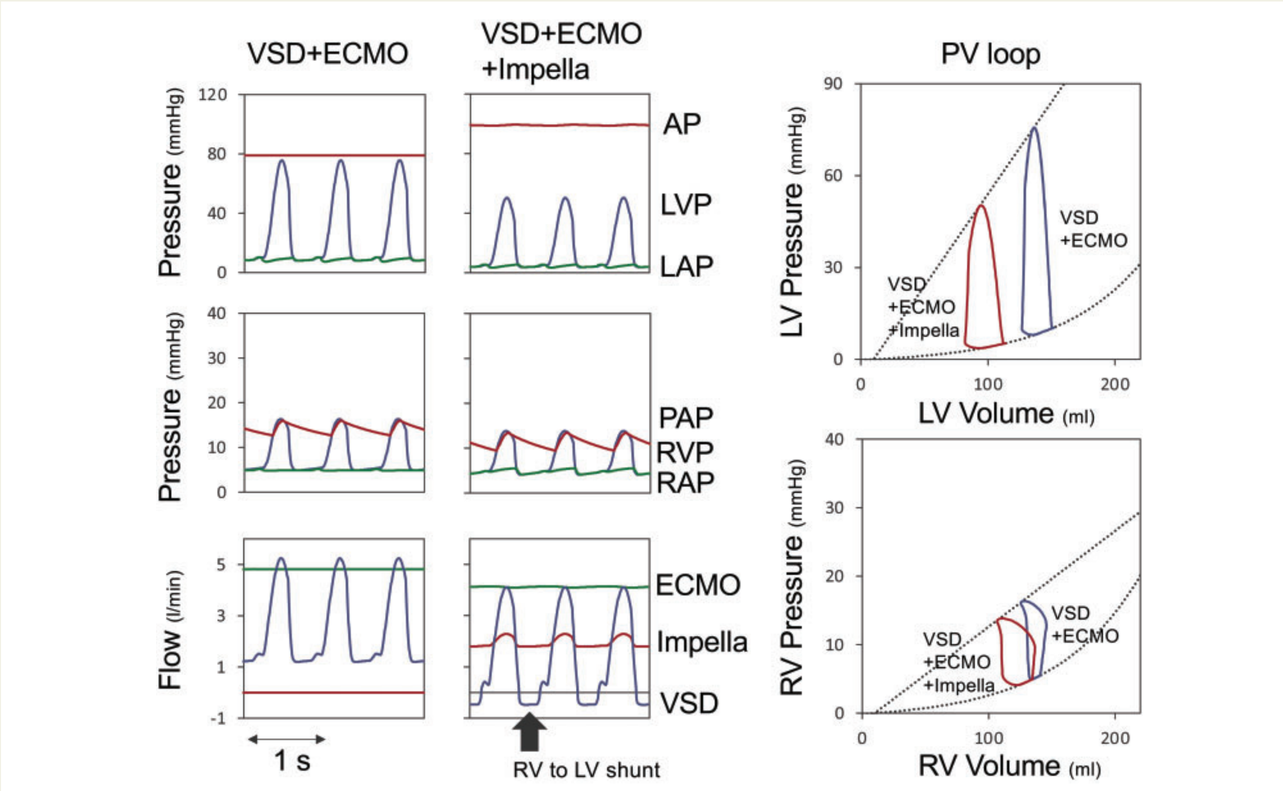


Figure 3 Haemodynamic simulation of mechanical circulatory support devices under ventricular septum defect in biventricular failure. Left and centre panels show haemodynamics under extracorporeal membrane oxygenation and extracorporeal membrane oxygenation + Impella support. The two right panels show the pressure–volume loop of the left and right ventricle. AP, atrial pressure; ECMO, extracorporeal membrane oxygenation; LAP, left atrial pressure; LVP, left ventricle pressure; PAP, pulmonary artery pressure; PV, pressure–volume; RAP, right atrial pressure; RVP, right ventricle pressure; VSD, ventricular septum defect.

cardiovascular simulator, each cardiovascular function was estimated from measured haemodynamics and echocardiography data. *Figure 3* presents the simulation of this case. Adding Impella to ECMO support induced the right-to-left VSD flow during diastole. Meanwhile in *Figure 4*, the absence of right ventricular failure diminished the right-to-left VSD flow. These data indicate that right ventricular failure in PIVSD may pose a risk for right-to-left VSD shunt after Impella. The three-dimensional chart shows the relationship between VSD and Impella–ECMO flow settings simulated by a cardiovascular simulator (parameter settings are described in Supplementary material online). The possibility of right-to-left VSD flow is higher in biventricular failure (*Figure 5B*) compared to left ventricular failure (*Figure 5A*). In addition, the simulation of *Figure 5B* indicates that our strategy, a decrease of Impella flow and an increase of ECMO flow, is a reasonable action to prevent right-to-left shunt after Impella in patients with PIVSD.

Conclusion

This case describes a rare condition: right-to-left shunt in a patient under ECPELLA support for PIVSD. A haemodynamic simulator shows that the right-to-left shunt is possibly caused by excess Impella flow in a patient with inferior PIVSD. This highlights the importance of frequent follow-up by echocardiogram and proper management of mechanical flow to protect against right-to-left shunt.

Lead author biography

Arudo Hiraoka is a chief director of cardiovascular surgery at the Sakakibara Heart Institute of Okayama in Japan. He involved in all field of cardiac, aortic, and endovascular surgeries. And he has always tried to ensure that he keeps himself productive in the field of research.

Supplementary material

Supplementary material is available at *European Heart Journal - Case Reports* online.

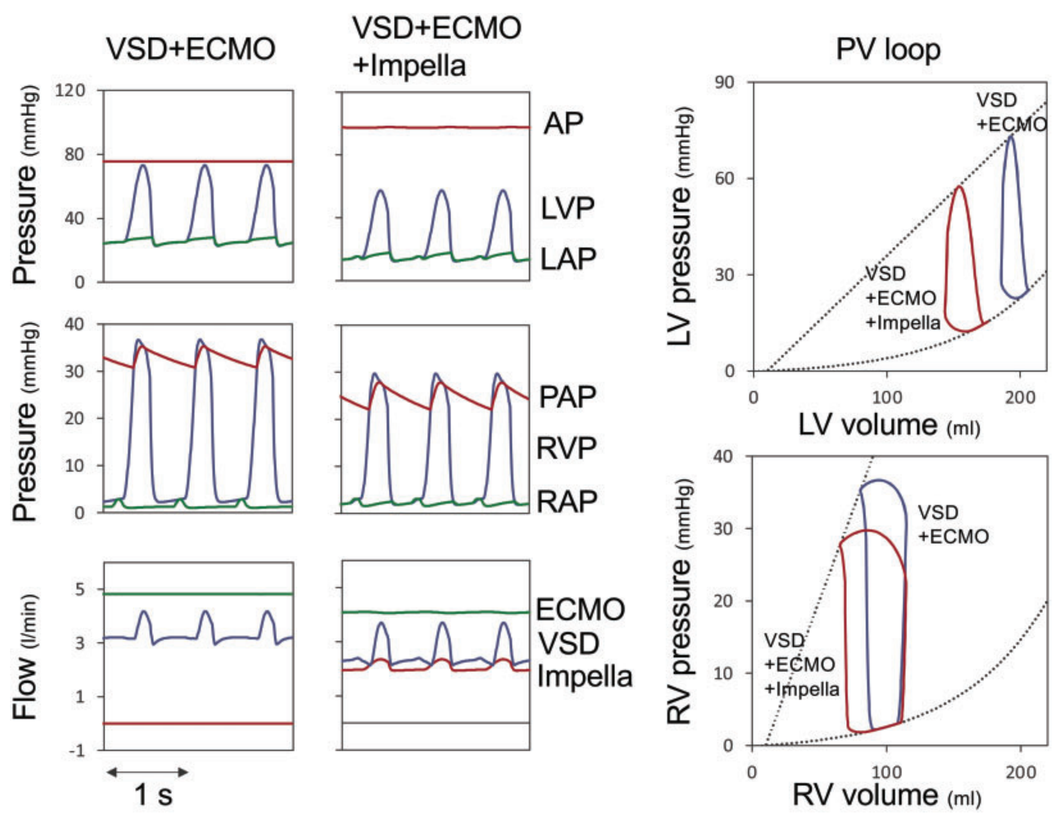


Figure 4 Haemodynamic simulation of mechanical circulatory support devices under ventricular septum defect in left ventricular failure. Left and centre panels show haemodynamics under extracorporeal membrane oxygenation and extracorporeal membrane oxygenation + Impella support. The two right panels show pressure–volume loop of left and right ventricle. AP, atrial pressure; ECMO, extracorporeal membrane oxygenation; LAP, left atrial pressure; LVP, left ventricle pressure; PAP, pulmonary artery pressure; PV, pressure–volume; RAP, right atrial pressure; RVP, right ventricle pressure; VSD, ventricular septum defect.

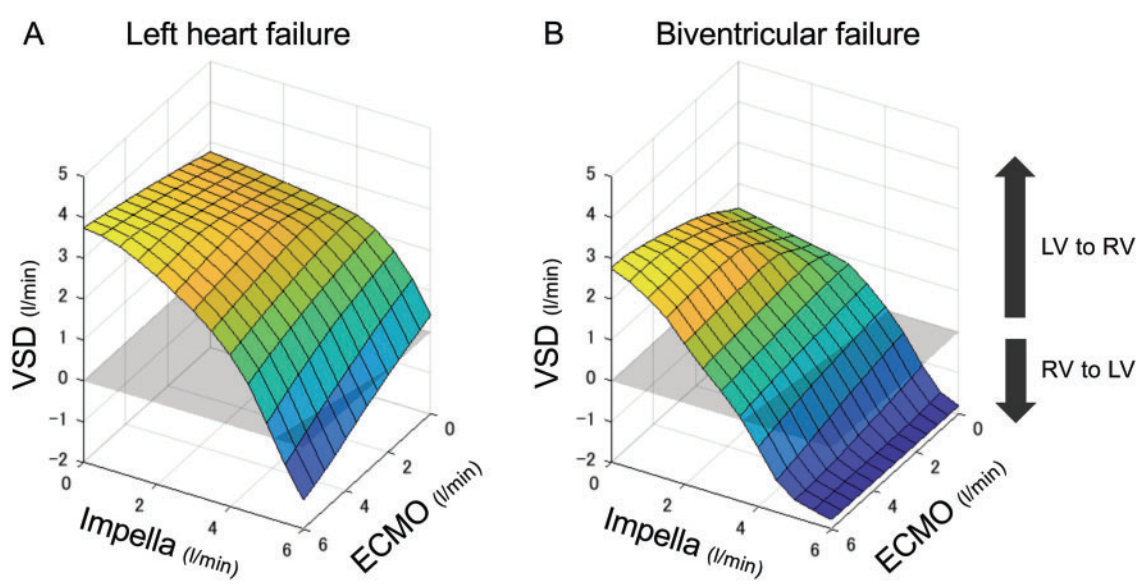


Figure 5 The impact of extracorporeal membrane oxygenation and Impella flow on ventricular septal defect flow under left (*A*) and biventricular (*B*) failure. *X*- and *Y*-axis show the flow of Impella and extracorporeal membrane oxygenation, respectively. *Z*-axis shows mean ventricular septal defect flow. ECMO, extracorporeal membrane oxygenation; LV, left ventricle; RV, right ventricle; VSD, ventricular septal defect.

Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written consent for submission and publication of this case report including images and associated text has been obtained from the patient in line with COPE guidance.

Conflict of interest: None declared.

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