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Original

Timing of Surgery under Mechanical Circulatory Support for Ventricular Septal Rupture Due to Acute Myocardial Infarction

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Summary

The optimal timing of acute myocardial infarction-associated ventricular septal rupture surgery is controversial. Therefore, we examined the appropriateness of our ventricular septal rupture surgical strategy for early surgery in absence of organ failure and delayed surgery after organ failure recovery. We retrospectively included 22 patients who underwent surgery for ventricular septal rupture between January 2012 and February 2021. After diagnosis, patients without organ failure underwent early surgery; those with organ failure underwent delayed surgery after organ failure recovery. In the early- (n = 17) and delayed-surgery (n = 5) groups, the mean ± standard deviation time from diagnosis to surgery was 0.3 ± 0.7 (0-2) and 5.2 ± 2.3 (3-8) days, respectively. The early-surgery group was treated with preoperative mechanical circulatory support using an intra-aortic balloon pump. The delayed-surgery group was treated with an Impella (n = 1), intra-aortic balloon pump combined with venous artery extracorporeal membrane oxygenation (n = 1), and Impella combined with venous artery extracorporeal membrane oxygenation (ECpella) (n = 3). The hospital and mid-term (52.1 ± 42.9 months) mortality rates were 9.1% (early-surgery group, 11.8%; delayed-surgery group, 0%) and 18.2% (early-surgery group, 23.5%; delayed-surgery group, 0%), respectively. Further, 70.6% and 82.4% patients without organ failure had cardiogenic shock and an anterior rupture location, respectively. In the early-surgery group, combined treatment with an intra-aortic balloon pump and medical therapy yielded hemodynamic stability until surgery. However, in patients with organ failure requiring long-term management, ECpella therapy was preferable, depending on the rupture size. Our treatment strategy was reasonable. Further research is warranted to determine the optimal support duration, especially for patients requiring long-term management.

Key Words: Extracorporeal membrane oxygenation, Impella, intra-aortic balloon pumping, myocardial infarction, ventricular septal rupture

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1. Introduction

Ventricular septal rupture (VSR) occurs in approximately 0.2-2% patients with acute myocardial infarction (AMI) and is often associated with cardiogenic shock (CS) and high mortality[1,2]. VSR most frequently occurs in the first 24 h or 3-4 days after AMI[1,3]. Surgical repair is the optimal treatment modality due to the limitations of drug therapy and the high mortality rate (> 90%)[2-4].

The mortality rate in cases of surgery for AMI-VSR repair may depend on the timing of surgery. Delayed surgery may result in more favorable outcomes than emergency surgery[5-9]. For delayed surgery, stabilization of hemodynamics and recovery of organ function are essential before surgery. Mechanical circulatory support (MCS) is frequently used as a bridge to surgery, improving systemic blood flow by increasing forward cardiac output (CO) and reducing shunting. Patients who do not receive MCS can develop unpredictable hemodynamics within hours or days of the onset of AMI-VSR, resulting in CS. Therefore, for surgical repair, MCS is required to maximize the patient's chances of survival and to prevent CS.

An intra-aortic balloon pump (IABP) and veno-arterial extracorporeal membrane oxygenation (VA-ECMO) are traditional MCS methods for VSR[5,10,11]. In 2017, the Impella (Abiomed, Danvers, MA, USA), a novel microaxial penetrating MCS device, was introduced in Japan. It is indicated for CS, mainly in drug-refractory acute heart failure cases, and is available in three versions: the Impella 2.5, CP, and 5.0. The Impella delays surgery in cases of AMI-VSR with CS[12,13]. Recently, related complications were reported. Hiraoka et al.[14] reported right-to-left shunting with deoxygenation of systemic perfusion with combined VA-ECMO and Impella (ECpella) treatment for VSR due to inferior wall infarction. Vila et al.[15] and Nishimura et al.[16] reported that aortic valve replacement is required in cases of severe aortic regurgitation due to tearing of the non-coronary cusp as a result of long-term treatment with the Impella.

The timing of surgery at our hospital is as follows: if there is no organ failure at the time of AMI-VSR diagnosis, the IABP is implanted and early surgery is performed; if organ failure is accompanied by CS, the Impella is used; otherwise, the patient is treated with IABP and surgery is delayed until the patient recovers from organ failure. If hemodynamics cannot be maintained due to right heart failure or hypoxemia, VA-ECMO is added; however, if organ failure worsens, early surgery is indicated. In this study, we aimed to examine the appropriateness of our VSR surgical strategy.

2. Materials and Methods

2.1 Patients

This was a single-center retrospective study. We consecutively included 22 patients who underwent cardiovascular surgery for AMI-VSR at our hospital between January 2012 and September 2021; patients who underwent reoperation for VSR recurrence were excluded.

The study protocol was approved by the Dokkyo Medical University Hospital Ethics Committee (approval No: R-47-9J). The study was conducted in accordance with the tenets of the Declaration of Helsinki. The need for written informed consent was waived due to the retrospective nature of the study.

VSR was diagnosed in all patients by transthoracic echocardiography, followed by emergency coronary angiography to identify the causative lesion. Percutaneous coronary angioplasty was performed in seven patients, all of whom underwent surgical treatment for VSR. At the time of diagnosis of AMI-VSR, if there was no organ failure, an IABP was implanted for early surgery; otherwise, support was provided by MCS until the patient recovered from organ failure. The Impella has been available in our hospital since April 2018, and its indications include CS.

2.2 Surgical procedure

Surgery was performed through a midline sternal incision with cardiopulmonary bypass. The VSR was approached from the infarcted area of the left ventricle and repaired using the "Daggett direct patch closure" or "Komeda-David infarct exclusion." The Daggett procedure is preferred at our hospital; the VSR is repaired using a large bovine pericardium or Hemashield patch. With the Komeda-David technique, a large patch of bovine pericardium is used to exclude the infarcted septum and free wall myocardium. Additional

Table 1 Baseline characteristics of early- and delayed-surgery groups

Characteristics	All n = 22	Early surgery group n = 17	Delayed surgery group n = 5
Age (mean ± SD), years	72.2 ± 9.4	71.2 ± 10.0	75.3 ± 2.1
Men, n (%)	10 (45.5)	7 (41.2)	3 (60.0)
BMI (mean ± SD), kg/m^2	22.0 ± 4.9	22.5 ± 5.4	20.5 ± 1.6
Culprit vessel			
RCA, n (%)	3 (13.6)	3 (17.6)	0
LAD, n (%)	19 (86.4)	14 (82.4)	5 (100)
AMI to VSR (mean ± SD), days	6.8 ± 7.6	8.0 ± 8.2	3.0 ± 2.6
VSR to surgery (mean ± SD), days	1.3 ± 2.4	0.3 ± 0.7	5.2 ± 2.3
Cardiogenic shock, n (%)	17 (77.3)	12 (70.6)	5 (100)
Preoperative			
IABP alone, n (%)	17 (77.3)	17 (100)	0
IABP + VA-ECMO, n (%)	1 (4.5)	0	1 (20.0)
Impella alone, n (%)	1 (4.5)	0	1 (20.0)
ECpella, n (%)	3 (13.6)	0	3 (60.0)
Blood tests			
AST (mean ± SD), U/L	321.2 ± 399.6	233.1 ± 316.6	873.3 ± 564.2
ALT (mean ± SD), U/L	200.7 ± 389.3	125.8 ± 213.0	718.3 ± 870.9
Total bilirubin (mean ± SD), mg/dL	1.1 ± 0.6	1.1 ± 0.6	1.4 ± 0.9
Creatinine (mean ± SD), mg/dL	1.3 ± 0.7	0.9 ± 0.2	2.6 ± 0.5
BNP (mean ± SD), pg/mL	1224.7 ± 989.7	1268.1 ± 1060.2	918.8 ± 803.1
CK (MAX) (mean ± SD), U/L	1515.6 ± 2187.4	1044.2 ± 1440.0	3986.3 ± 4608.7
CK-MB (mean ± SD), U/L	110.5 ± 255.5	50.1 ± 91.4	404.3 ± 649.3
Lactic acid (mean ± SD), mmol/L	2.6 ± 1.4	2.2 ± 1.3	4.6 ± 1.0

SD, standard deviation; BMI, body mass index; RCA, right coronary artery; LAD, left anterior descending artery; AMI, acute myocardial infarction; VSR, ventricular septal rupture; IABP, intra-aortic balloon pump; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; ECpella, combined Impella and VA-ECMO; AST, aspartate aminotransferase; ALT, alanine aminotransferase; BNP, brain natriuretic peptide; CK, creatine kinase; CK-MB, creatine kinase-MB.

coronary artery bypass grafting (CABG) was performed if substantial coronary artery stenosis was present.

2.3 Assessment parameters

CS was diagnosed using established criteria: systolic blood pressure (BP) < 90 mmHg, use of inotropic drugs, heart rate > 100 or < 60 beats per minute (bpm), and serum lactate > 2 mmol/L. Organ failure was evaluated with laboratory data, chest x-ray, and blood gas analysis. The following criteria were set: serum creatinine > 3 mg/dl or oliguria for renal failure, serum bilirubin > 3.0 mg/dl for liver failure, and PaO_2 < 60 mmHg or pulmonary congestion for respiratory failure. Early surgery was defined as surgery undertaken within 2 days of diagnosis. Perioperative complications were identified in patients who survived the surgery.

2.4 Statistical analyses

Continuous variables are presented as means ± standard deviations, and categorical variables are presented as counts and proportions. The 5-year survival rate was calculated using Kaplan-Meier analysis. IBM SPSS Statistics software version 27.0 (IBM Corp., Armonk, NY, USA) was used for statistical analyses.

3. Results

3.1 Baseline characteristics

Table 1 summarizes the baseline characteristics of the study sample. Their mean age was 72.2 ± 9.4 years and 10 patients were men. The mean periods from AMI to VSR diagnosis and from diagnosis to surgery were 6.8 ± 7.6 and 1.3 ± 2.4 days, respectively.

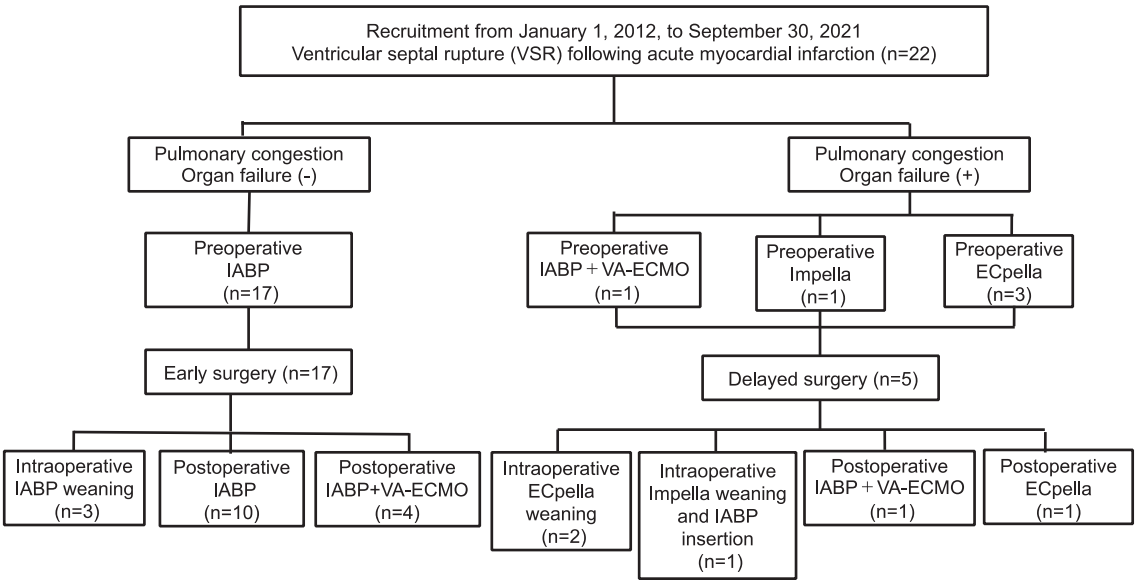

Figure 1 Flow diagram of the present study
IABP, Intra-aortic balloon pump; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; ECpella, VA-ECMO and concomitant Impella support

Seventeen and five patients underwent early and delayed surgery, respectively (Fig. 1). The causes of delayed surgery included renal failure alone and both renal and respiratory failures in one and four patients, respectively. The mean times from diagnosis to surgery in the early- and delayed-surgery groups were 0.3 ± 0.7 (0-2) and 5.2 ± 2.3 (3-8) days, respectively. CS occurred in 12 patients in the early-surgery group and in all five patients in the delayed-surgery group. Preoperative MCS support included IABP alone in 17 patients, combined IABP and VA-ECMO in one patient, an Impella in one patient, and ECpella in three patients (Fig. 1). Preoperative mean laboratory values for aspartate aminotransferase, alanine aminotransferase, creatinine, lactate, creatinine kinase (CK) maxima, and CK-MB levels were higher in the delayed-surgery group.

3.2 Treatment

Table 2 shows the treatments for each group. Percutaneous coronary intervention was performed for coronary artery reconstruction in six patients and one patient in the early- and delayed-surgery groups, respectively. The original plan was to operate patients with organ failure after 2 weeks, allowing for recovery. Two patients with worsening organ failure underwent surgery 3 days after diagnosis, and three patients treated with ECpella showed organ recovery but were operated after 5-8 days because of ECpella-induced bleeding. Three patients had Impella-related bleeding (one gastrointestinal and two at the catheter insertion site), and one suffered cerebral infarction. The VSRs were located on the anterior and posterior walls in 19 (86.4%) and three (13.6%) patients, respectively. Seventeen patients underwent VSR repair alone, and five (22.7%) underwent combined CABG. There were no differences between the two groups in the mean operative time, mean cardiopulmonary bypass time, or mean aortic cross-clamp time. Most of the surgical procedures were performed with the Daggett technique (13 undergoing early surgery, four delayed). Three patients were weaned intraoperatively from the IABP, two from VA-ECMO, and three from the Impella. Eleven patients required a postoperative IABP, five required combined IABP and VA-ECMO, and one required ECpella (Fig. 1). The mean duration of use for the 16 patients who used a postoperative IABP was 4.6 ± 4.8 days; five patients used VA-ECMO for 5.0 ± 4.0 days, and one used the Impella for 8 days.

3.3 Early outcomes

Hospital mortality was observed in two patients (9.1%). Concerning surgical timing, 11.8% patients were included in the early-surgery group and none were included in the delayed-surgery group. The first was a

Table 2 Treatment of early- and delayed-surgery groups

Characteristics	All n = 22	Early surgery group n = 17	Delayed surgery group n = 5
PCI (DES) procedure	7 (31.8)	6 (35.3)	1 (20.0)
RCA, n (%)	1 (4.5)	1 (5.9)	0
LAD, n (%)	6 (27.3)	5 (29.4)	1 (20.0)
Complication (preoperative)			
Device-related bleeding, n (%)	3 (13.6)	0	3 (60.0)
Stroke, n (%)	1 (4.5)	0	1 (20.0)
Location of VSR			
Anterior, n (%)	19 (86.4)	14 (82.4)	5 (100)
Posterior, n (%)	3 (13.6)	3 (17.6)	0
Surgical procedure			
Daggett, n (%)	17 (77.3)	13 (76.5)	4 (80.0)
Komeda-David, n (%)	3 (13.6)	2 (11.8)	0
Double patch technique, n (%)	1 (4.5)	0	1 (20.0)
VSR direct-closure, n (%)	1 (4.5)	1 (5.9)	0
Combined CABG, n (%)	5 (22.7)	3 (17.6)	2 (40.0)
Surgery time (mean ± SD), min	320.6 ± 98.9	318.2 ± 105.6	328.8 ± 81.5
CPB time (mean ± SD), min	161.6 ± 48.4	162.8 ± 50.9	157.6 ± 43.7
Aortic crossclamp time (mean ± SD), min	119.6 ± 33.6	120.2 ± 33.7	117.6 ± 37.3
Postoperative			
IABP, n (%)	11 (50.0)	10 (58.8)	1 (20.0)
IABP (combined VA-ECMO), n (%)	5 (22.7)	4 (23.5)	1 (20.0)
ECpella, n (%)	1 (4.5)	0	1 (20.0)
Duration of IABP (mean ± SD), days	4.6 ± 4.8	4.9 ± 5.1	2.5 ± 0.7
Duration of VA-ECMO (mean ± SD), days	5.0 ± 4.0	6.3 ± 5.5	3.0 ± 2.8
Intubation time (mean ± SD), hours	184.0 ± 132.9	178.9 ± 141.2	201.6 ± 112.1
ICU stay (mean ± SD), days	12.0 ± 9.9	11.4 ± 9.9	14.2 ± 12.0
Follow-up period, (mean ± SD), months	52.1 ± 42.9	56.4 ± 42.6	37.6 ± 45.5

SD, standard deviation; PCI, percutaneous coronary intervention; DES, drug eluting stents; RCA, right coronary artery; LAD, left anterior descending artery; VSR, ventricular septal rupture; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; IABP, intra-aortic balloon pump; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; ECpella, combined Impella and VA-ECMO; ICU, intensive care unit.

77-year-old woman, diagnosed with intestinal bleeding because of melena on postoperative day (POD) 33. She underwent intestinal resection, but died on POD 44 due to rebleeding. The other was a 54-year-old man who developed two recurrences of VSR. He underwent repeated surgery, but died of low output syndrome on POD 120. Autopsy revealed extensive myocardial infarction, and the outflow of the right ventricle was almost obstructed by the fused felts used for patch closure via the Daggett technique. The major postoperative complications were long-term ventilator management in 16 patients (12 undergoing early surgery, four delayed), new induction of dialysis in two, and tracheostomy, cerebral infarction, renal infarction, and peripheral vascular complications in one each. Intraoperative transesophageal echocardiography showed no residual shunts, but postoperative shunt recurrence was observed in five patients (three undergoing early surgery, two delayed) and new VSR in one patient; these six patients (four undergoing early surgery, two delayed) underwent reoperation (Table 3).

3.4 Mid-term survival

The follow-up period was 52.1 ± 42.9 (range: 1-122) months, with a cumulative survival rates of 95.5% at 30 days, 90.4% at 12 months, 85.2% at 24 months, and 78.7% at 36 and 60 months (Fig. 2). The mid-term deaths were four patients (four patients in the early-

Table 3 Early and mid-term outcomes of early- and delayed-surgery groups

Characteristics	All n = 22	Early surgery group n = 17	Delayed surgery group n = 5
Hospital death, n (%)	2 (9.1)	2 (11.8)	0
Complications			
Intubation time > 72 h, n (%)	16 (72.7)	12 (70.6)	4 (80.0)
Tracheostomy, n (%)	1 (4.5)	1 (5.9)	0
Stroke, n (%)	2 (9.1)	0	2 (40.0)
Dialysis, n (%)	2 (9.1)	2 (11.8)	0
Renal infarction, n (%)	1 (4.5)	1 (5.9)	0
Peripheral vascular dissection (by Impella), n (%)	1 (4.5)	0	1 (20.0)
Recurrent VSR shunt, n (%)	5 (22.7)	3 (17.6)	2 (40.0)
New VSR shunt, n (%)	1 (4.5)	1 (5.9)	0
Reoperation, n (%)	6 (27.2)	4 (23.5)	2 (40.0)
Mid-term death, n (%)	4 (18.2)	4 (23.5)	0

SD, standard deviation; LOS, low output syndrome.

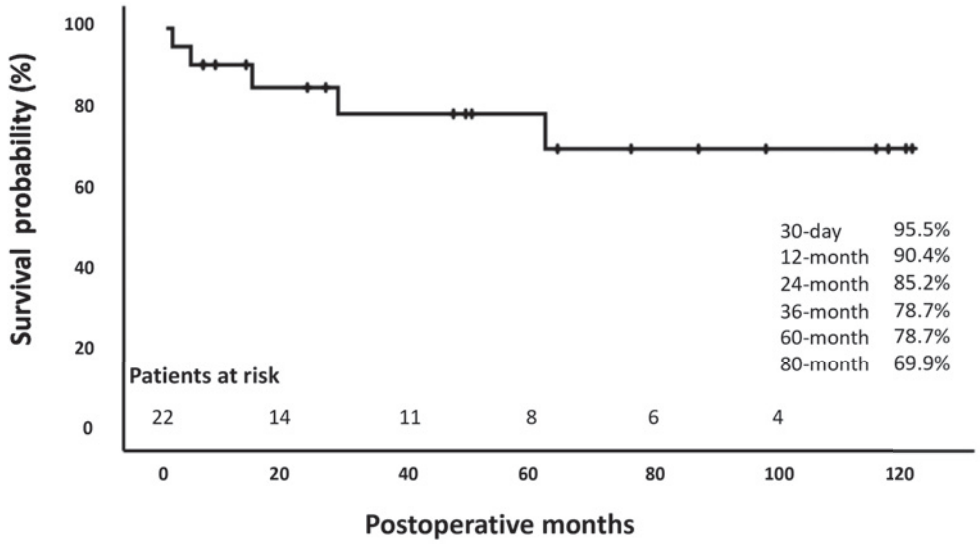

Figure 2 Kaplan-Meier survival curve following repair of a ventricular septal rupture with CS
CS, cardiogenic shock

surgery group and none in the delayed-surgery group). Deaths were attributed to intestinal hemorrhage (one patient on POD 44), low output syndrome (one patient on POD 120), cancer (one patient at 1 year postoperatively), and pneumonia (one patient at 2 years postoperatively).

3.5 Effectiveness of the Impella

Patient 1:

A 76-year-old man with two-vessel disease had a posterior VSR (3.0 × 5.0 cm^2) on day 5 post-AMI. Impella implantation was performed; however, since his hemodynamics remained unstable, VA-ECMO was added immediately after Impella implantation. His renal function was severely impaired. The Impella was controlled at a flow rate of 1.5-2.5 L/min (P4-6). ECpella therapy was initiated, and the patient's renal function and hemodynamics recovered the next day; however, melena and convulsions developed on POD 5. As we believed that further complications would develop, we performed VSR repair and CABG on POD 6 to wean the patient off the ECpella. However, complications de-

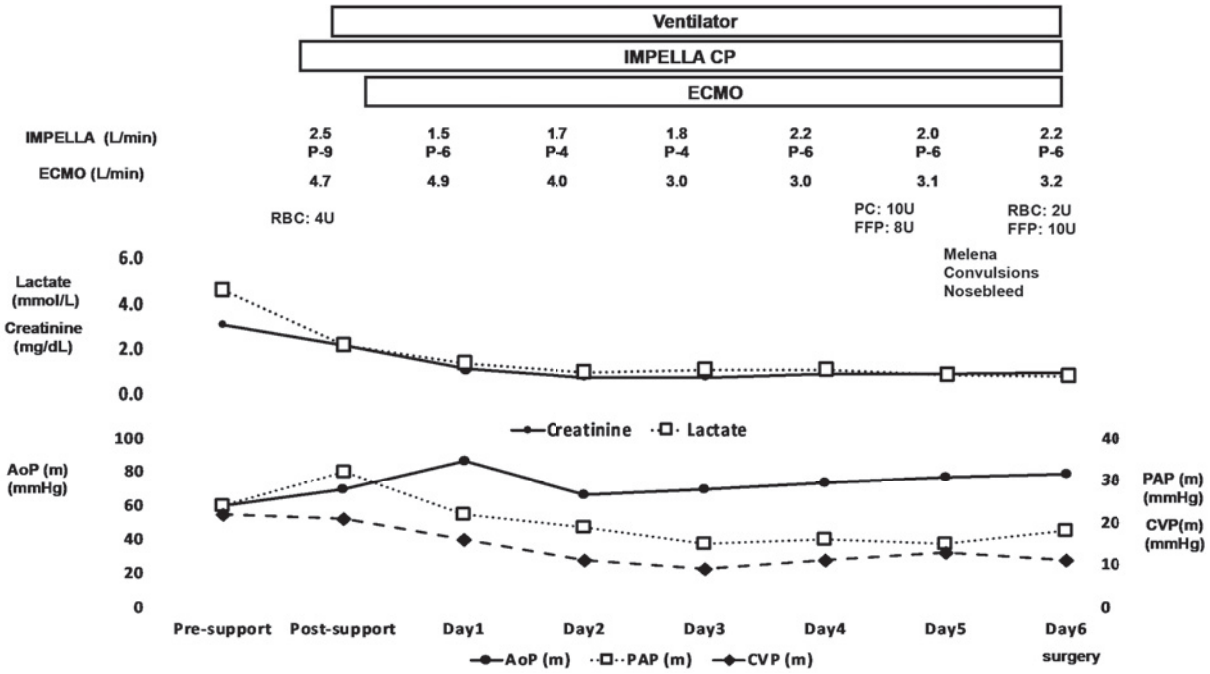

Figure 3 Clinical course of a 77-year-old woman (Patient 1) who underwent preoperative Impella treatment
AoP, aortic pressure; CVP, central venous pressure; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; FFP, fresh-frozen plasma; PAP, pulmonary artery pressure; PC, platelet concentrates; RBC, red blood cells

veloped, including cerebral infarction, rectal ulcer hemorrhage, and peripheral vascular occlusion, requiring additional treatment (Fig. 3).

Patient 2:

A 77-year-old woman with two-vessel disease had an anterior VSR (1.5 × 1.5 cm^2) on day 4 post-AMI. Her hemodynamic condition was stabilized through administration of dobutamine (5.0 μg/kg/min) and noradrenaline (0.02 μg/kg/min). An Impella was implanted and maintained at a flow rate of 1.9-2.9 L/min (P6). However, on POD 2, the patient developed pulmonary congestion and underwent combined VA-ECMO. After ECpella treatment, her renal and hepatic functions gradually improved; unfortunately, thrombocytopenia and anticoagulation therapy caused uncontrolled bleeding at the Impella insertion site. We determined that further complications had developed, and medical therapy was not feasible; hence, VSR repair and CABG were performed on day 7 after Impella therapy, and the patient was weaned from ECpella at the same time.

4. Discussion

In this study, all patients received preoperative MCS support. Moreover, Impella support was effective in recovering from organ failure, but hemorrhagic complications requiring blood transfusion were observed. In addition, the hospital mortality rate was 9.1%, with early surgery accounting for 77.3% cases, which was a favorable result.

Medical therapy for AMI-VSR includes inotropic agents, vasodilators, and vasoconstrictors. Vasodilators are suitable for reducing shunt flow and the pulmonary/systemic blood flow ratio (Qp:Qs), but not in isolation because they lower systemic BP. Inotropic agents increase BP and CO, but also considerably increase shunt flow and pulmonary artery pressure. In contrast, vasoconstrictors increase systemic BP but increase shunt flow, decrease systemic perfusion, and decrease mixed venous saturation. These in combination do not improve the overall hemodynamics.

In the GUSTO-I trial, the mortality rate among 35 patients with VSR who were treated without surgery was very high (94%)[2], and the importance of hemodynamic stabilization using MCS before surgical treatment was demonstrated. However, most reports to date have indicated the use of MCS for cases of delayed surgery. The percutaneous MCS systems avail-

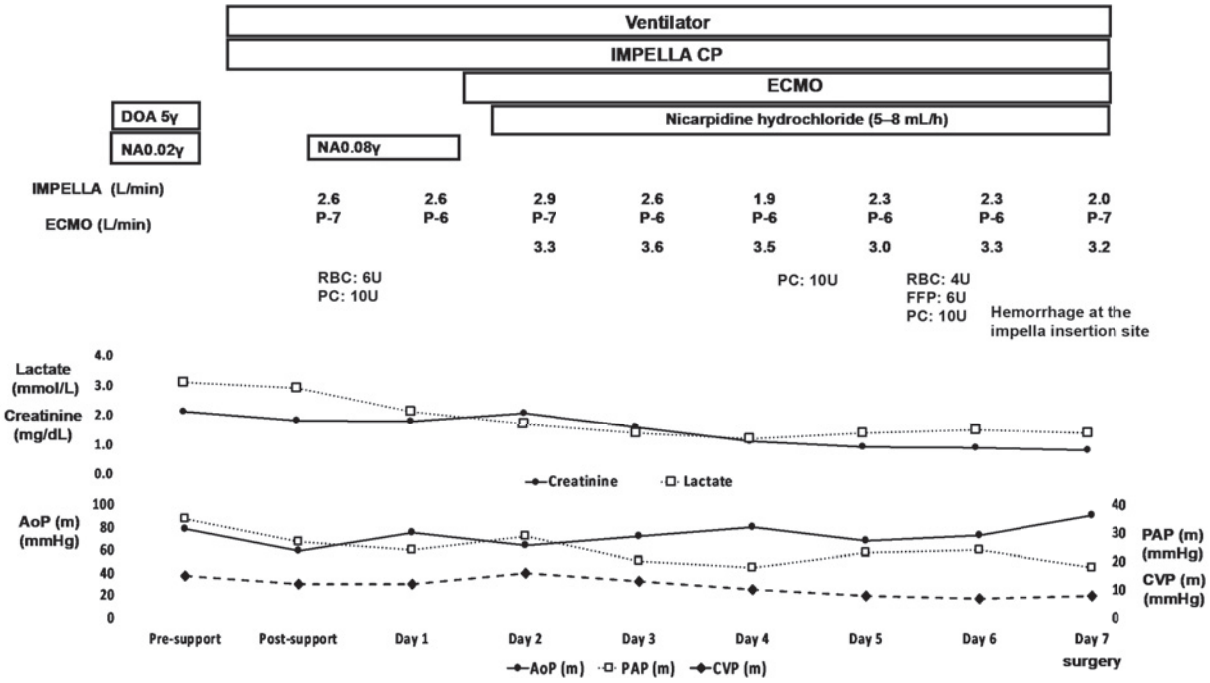

Figure 4 Clinical course of a 54-year-old man (Patient 2) who underwent preoperative Impella treatment
AoP, aortic pressure; CVP, central venous pressure; DOA, dopamine; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; FFP, fresh-frozen plasma; NA, noradrenaline; PAP, pulmonary artery pressure; PC, platelet concentrates; RBC, red blood cells

able in Japan are IABP, VA-ECMO, and the Impella. Pressure and flow throughout the cardiovascular system have been reported with percutaneous MCS in an AMI-ventricular septal defect (VSD) simulation using a well-validated computational model[17]. A left-to-right shunt of the VSD was associated with progressive abbreviation of the isovolumic contraction phase, increased total stroke volume, decreased systemic flow, and decreased pressure generation. The increase in VSD size also increased shunt flow, pulmonary flow, pulmonary capillary wedge pressure (PCWP), LV end-diastolic volume, and the Qp:Qs. With IABP therapy, the balloon was deflated during systole to decrease the effective arterial afterload and promote ejection through the aortic valve. Accordingly, the total blood flow to the body increased and shunt flow decreased, thus decreasing the Qp:Qs; however, the overall effect was small. In another study, when using an IABP and respiratory support between the time of VSR diagnosis and surgery, 54.2% surgeries were delayed for an average of 9 days. The 30-day mortality rate in their cohort was 4.2%, the operative mortality rate was 12.5%, and the repeated surgery rate was 20.8%[18]. In our retrospective study, most patients who underwent early surgery were operated within 24 h of diagnosis, with preoperative IABP and medical therapy support, and 70.6% patients experienced CS. In the early-surgery group, there were no cases of sudden deterioration during the waiting period for surgery or induction of anesthesia, suggesting that an IABP may be effective when combined with medical therapy, even if the effect is small.

The Impella has been available in Japan since 2017. It causes recovery of the myocardium by left ventricular unloading and increasing the systemic blood volume, mean arterial pressure (MAP), and coronary blood flow. The Impella decreases left-to-right shunting of the AMI-VSR and increases CO[13]. It also delays surgery in cases of posterior VSR with CS[12]; the interval between Impella treatment and surgery was 8-23 days[13,19,20], longer than that between IABP treatment and surgery. The purpose of such a delay, besides recovery from organ failure and stabilizing hemodynamics, is to allow the formation of fibrous tissues that are conducive for suturing at the infarcted area. Similarly, in the AMI-VSD simulation study[17], the Impella in-

creased the total blood flow to the body and significantly decreased flow through the VSR but had little effect on PA flow. The PV loop shifted left toward lower filling pressures and volumes, but the peak LV pressure increased minimally. Pahuja et al.[17] reported that ECpella is the most hemodynamically stable MCS for AMI-VSD. VA-ECMO markedly improved total blood flow and increased oxygen saturation, but also increased shunt flow. In addition, the PCWP increased due to an increase in LV afterload. ECpella therapy provides maximum overall circulatory support and unloading of the LV as the Impella compensates for the shortcomings of VA-ECMO. In addition, because the Impella 5.0 decreases the shunt flow, mean PA pressure, and PCWP and increases MAP and CO more than Impella CP, the best MCS support for VSR is ECpella therapy with the Impella 5.0.

According to La Torre et al.[12], hemodynamics stabilized the day after Impella 5.0 implantation, and blood analysis showed recovery to a normal state after 2 weeks; thus, a 2-week treatment period after Impella implantation may be appropriate. In the present study, all patients were implanted with the Impella CP. However, one patient underwent emergency surgery because of decreased urine output and worsening renal function the day after implantation. The other patient was treated with the Impella alone, but on the second day, VA-ECMO was added due to pulmonary congestion and hemodynamic instability. We cannot say with certainty, due to our small sample size, but similar to the results of Pahuja et al.[17], it seems that ECpella therapy is best suited for hemodynamic maintenance of AMI-VSR with CS, as the Impella alone is likely to be complicated by right heart failure, eventually. However, the Impella 5.0 requires a surgical procedure and is not suitable for emergency surgery. Therefore, the ideal strategy is to initiate ECpella treatment with the Impella CP and subsequently change to the Impella 5.0 if the patient does not recover from organ failure. Long-term use of MCS is connected with a variety of complications, including bleeding, sepsis, and death[21], with significantly more severe bleeding and peripheral vascular complications occurring when using the Impella than when using an IABP[22,23]. In our study, the average time from VSR diagnosis to surgery in the delayed-surgery group was 5.2 ± 2.3 days, shorter than the planned 2 weeks due to bleeding complications. This problem arose due to failure to control the bleeding complications caused by ECpella anticoagulation. The combined use of MCS possibly led to a decreased platelet count and further aggravated bleeding complications. Further, Flier et al.[24] reported that 95% patients receiving Impella therapy developed acquired von Willebrand syndrome (AVWS), suggesting that AVWS is a common phenomenon during left ventricular unloading via microaxial pump support. AVWS must be considered as a contributing factor to potential bleeding complications in Impella treatment.

The interval between the diagnosis of VSR and surgical repair has been associated with mortality. The hospital mortality rate in six studies on patients with VSR who underwent surgery within 3 days was 51.4-100%; in five studies on patients who underwent surgery within 3-7 days, it was 11-75%; and in seven studies on patients who underwent surgery after 7 days, it was 0-18.4%[5-9,25-29]. Furthermore, patients with preoperative CS had a poor prognosis, with hospital mortality rates of 52-100%[5-8]. In the present study, the mean time from diagnosis of VSR to surgery was 0.3 ± 0.7 (0-2) and 5.2 ± 2.3 (3-8) days for the early and delayed-surgery groups, respectively; 17 (77.3%) patients underwent early surgery. The timing of surgery, including delayed surgery, was earlier compared to that in other studies, with a hospital mortality rate of 9.1% (two patients) and only one case of cardiac-related death. The results of the early surgery performed within 2 days were better than those reported for surgery performed within 7 days[5-9,25-29], and the timing of surgery was good considering the MCS-related hemorrhagic complications and other complications during the period of delayed surgery. In contrast, the delayed-surgery group could not be delayed to the originally planned 2 weeks, with a maximum duration of 8 days. The timing of surgery was immediately after recovery from organ failure. However, although there were no hospital deaths, the shunt recurrence rate was higher in the delayed-surgery group (40%) than in the early-surgery group (17.6%). This was attributed to extensive myocardial infarction, with higher CK and CK-MB levels at diagnosis in the delayed-surgery group than in the early-surgery group. At the time of surgery, the VSR was clearly visible, but the tissue was fragile. In

cases of organ failure, waiting for tissue fibrosis may have prevented shunt recurrence. Determining the optimal timing of surgery is important considering the advantages and disadvantages of MCS and the timing of surgery.

4.1 Limitations

This study has several limitations. First, the study had a very small sample size due to the low incidence of AMI-VSR. Second, we could not adequately assess Impella treatment efficacy due to the small sample size (n = 4). Thus, a comparative study with a larger sample size and longer follow-up duration is needed to evaluate the effectiveness of our treatment strategy.

Based on our findings, the surgical strategy with VSR was appropriate. When long-term management is required, the combination with VA-ECMO rather than the use of an IABP or the Impella alone may be the best support for AMI-VSR. However, further research is needed to determine the optimal duration of assistance for high-risk patients.

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Author contributions

All the authors have substantially contributed to the design of the work. IS performed the analysis. IS, HO, and HF drafted the work and did critical revision. All the authors gave final approval and agreed to be accountable for all aspects of the work in question related to the accuracy of the content.

Conflict of interest

The authors declare that there is no conflict of interest.

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