Impella support as a bridge to heart surgery in patients with cardiogenic shock

Shunsuke Saito*, Ikuko Shibasaki, Taiki Matsuoka, Ken Niitsuma, Shotaro Hirota, Yasuyuki Kanno, Yuta Kanazawa, Masahiro Tezuka, Yusuke Takei, Go Tsuchiya, Taisuke Konishi, Koji Ogata and Hirotsugu Fukuda

Department of Cardiac and Vascular Surgery, Dokkyo Medical University, Mibu, Japan

* Corresponding author. Department of Cardiovascular Surgery, Dokkyo Medical University, 880 Kitakobayashi, Mibu, Shimotsugagun, Tochigi 321-0293, Japan. Tel: +81-282-86-1111; fax: +81-282-86-2022; e-mail: saitos@dokkyomed.ac.jp (S. Saito).

Received 31 December 2021; received in revised form 18 March 2022; accepted 22 March 2022

Abstract

OBJECTIVES: In patients with cardiogenic shock, delayed surgery after stabilization of hemodynamics and improvement in end-organ function by mechanical circulatory support is known to yield better outcomes than emergency surgery. We aimed to investigate the effectiveness of Impella (Abiomed, Danvers, MA, USA) as a bridge to cardiac surgery in patients with cardiogenic shock.

METHODS: We reviewed 7 patients with cardiogenic shock who underwent Impella support as a bridge to cardiac surgery using cardiopulmonary bypass at our institution between April 2018 and August 2021.

RESULTS: Cardiogenic shock was caused by ventricular septal rupture in 3 patients, papillary muscle rupture in 1 and acute myocardial infarction in 3. Cardiac surgery was delayed by 1–7 (3.9 ± 2.5) days with Impella support after the diagnosis of cardiogenic shock, during which the hepatic and renal function of the patients improved significantly. Device-related or operation-related adverse events included re-exploration for bleeding in 3 patients, acute limb ischaemia due to thromboembolism in 1 and intraoperative aortic dissection in 1.

Key question

Is Impella useful as a bridge to surgery in patients with cardiogenic shock?

Key finding(s)

Impella improved end-organ function preoperatively and a 30-day mortality rate was 14.3% after surgery.

Take-home message

Impella is an effective tool for bridging patients with cardiogenic shock to heart surgery.

Survival Analysis

30-day mortality: 14.3%
Cumulative survival: 71.4% (1 year)

85.7% 71.4%
61.5% 30.8%
Bridged with Impella / ECMPELLA (n = 7)
Bridged with ECMO (n = 13)
P = 0.0992

Patients at risk
Impella 7
ECMO 13

© The Author(s) 2022. Published by Oxford University Press on behalf of the European Association for Cardio-Thoracic Surgery. This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (https://creativecommons.org/licenses/by-nc/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
Thirty-day mortality was 14.3%, and the cumulative survival was 71.4% at 1 year. The survival tended to be better than that in historical control group in which extracorporeal membrane oxygenation was used as a bridge to surgery (P = 0.0992).

**CONCLUSIONS:** Impella is an effective tool for bridging patients with cardiogenic shock to surgery. This strategy may improve surgical outcomes in patients with cardiogenic shock. However, prolonged Impella support may increase significant adverse events, and further investigation is required to determine the optimal duration of support before surgery.

**Keywords:** Impella • Cardiogenic shock • Delayed surgery • Emergency surgery • Bridge to surgery

| ABBREVIATIONS |
|----------------|
| CT | Computed tomography |
| ECMO | Extracorporeal membrane oxygenation |
| ECPELLA | Extracorporeal membrane oxygenation + Impella |
| IABP | Intra-aortic balloon pump |
| Pt. No | Patient number |
| STS-PROM | Society of Thoracic Surgery-Predicted Risk of Mortality |

**INTRODUCTION**

Emergency heart surgery using cardiopulmonary bypass in patients with cardiogenic shock is associated with high mortality and poor clinical outcomes [1–3]. Operative mortality in patients with cardiogenic shock is as high as 40–100% [1–3]. Delayed surgery after stabilization of haemodynamics and improvement in end-organ function by temporary mechanical circulatory supports has been reported to yield better results than emergency surgery in such cases [1, 3–6].

Recently, Impella (Abiomed, Danvers, MA, USA), a percutaneous axial-flow left ventricular assist device, has been introduced as a promising bridge tool to transiently support patients’ haemodynamics [7, 8]. Although the usefulness of Impella in patients with decompensated heart failure as a bridge to recovery, a bridge to durable devices or a bridge to transplantation has been well documented [8], its usefulness as a bridge to open-heart surgery in patients with cardiogenic shock has only been reported as case reports [9–15] or as small cohort reports [16]. Moreover, tips on device management during aortic cross-clamping have not yet been reported.

This study aimed to evaluate the effectiveness of Impella as a bridge to open-heart surgery in patients with cardiogenic shock.

**METHODS**

**Ethics statement**

This retrospective study was approved by the Institutional Review Board of Dokkyo Medical University, Japan (15 June 2021, reference number: R-47-9). Written informed consent for participation in this study was waived because of anonymity.

**Patients**

From April 2018 to August 2021, 86 patients underwent Impella support at our institution. Nine of them were supported with Impella as a bridge to heart surgery using cardiopulmonary bypass. All 9 patients had cardiogenic shock status before Impella insertion. Cardiogenic shock was diagnosed using the following established criteria: (i) systolic blood pressure <90 mmHg for >30 min or vasopressors required to achieve blood pressure >90 mmHg; (ii) pulmonary congestion or increased left ventricular filling pressure; and (iii) signs of impaired organ perfusion with at least one of the following criteria: (a) altered mental status, (b) cold, clammy skin, (c) oliguria and (d) increased serum lactate [17]. Two patients were bridged to durable left ventricular assist device implantation and were excluded from this study. The remaining 7 patients were included in this study. Data were extracted from patient charts recorded in the hospital computer database.

**Impella management during surgery**

During the surgery, cardiopulmonary bypass was established between ascending aorta and bicaval cannulation in all the cases. In the patients who were supported with extracorporeal membrane oxygenation (ECMO) in addition to Impella preoperatively, ECMO was stopped after the establishment of cardiopulmonary support. Before aortic cross-clamping, epiaortic echocardiography was performed to detect the precise position of the Impella. If the pump motor portion or blood outflow portion was positioned at the aortic cross-clamp site, the Impella was advanced forward until the catheter shaft of the Impella was positioned at the clamp site (Fig. 1). The Impella pump speed was set at P1, and the aorta was cross-clamped. The initial cardioplegic solution was administered antegrade. The aortic root was palpatated and if the aortic root pressure was not high enough, the Impella pump speed was increased to P2. After completing the initial antegrade cardioplegia, Impella was set in ‘surgical mode’. Maintenance cardioplegia was administered retrogradely.

The surgical mode was stopped before declamping the aorta. The aortic root vent was opened, and the Impella pump speed was cycled between P0 and P1 to eliminate intracardiac air. After adequate deairing, the aorta was declamped.

The Impella position was readjusted using transoesophageal echocardiographic guidance. Cardiopulmonary bypass support was gradually decreased and the speed of the Impella pump was gradually increased. If adequate Impella flow to wean off the cardiopulmonary bypass was not achieved due to right heart failure (characterized by elevated central venous pressure, dilated right ventricle and small left ventricle and frequent suction event of Impella), veno-arterial ECMO support was added.

After weaning off the cardiopulmonary bypass, heparin was fully reversed. Postoperatively, continuous heparin infusion was restarted once stable haemostasis was achieved.

**Statistical analysis**

Continuous variables are presented as mean ± standard deviation. The pre-Impella and post-Impella values of laboratory data
were compared using paired Student’s t-tests. Time-to-event analyses were performed using Kaplan–Meier estimates and compared with the use of the log-rank test. All two-sided P-values <0.05 were considered statistically significant. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics [18].

RESULTS

Patient profile

The clinical characteristics of the 7 patients are summarized in Table 1. Six of the 7 patients were males. The mean age of the patients was 75 ± 5.9 years. All patients had an acute myocardial infarction. Cardiogenic shock was caused by ventricular septal rupture in 3 patients, papillary muscle rupture in 1 and acute myocardial infarction in 3. Operative mortality risk was high in all patients, with a mean Society of Thoracic Surgery-Predicted Risk of Mortality (STS-PROM) score of 25.2 ± 9.7 (15.6–45.1). Three patients [patient number (Pt. No.) 1, 3 and 4 in Table 1] required ECMO support in addition to Impella support (ECPELLA) [19, 20]. In all the 3 patients, veno-arterial ECMO support was added after the initiation of Impella support because of inadequate Impella support due to right heart failure (elevated central venous pressure, inadequate Impella flow, and frequent suction event). The type of Impella was Impella CP in all the 7 patients. The pump speed, representative flow of Impella during Impella support, ECMO flow in ECPELLA patients, and cardiac index (thermodilution method) of the right heart catheter in patients without ECMO are summarized in Table 1.

Improvement in end-organ function

Curative surgery using cardiopulmonary bypass was delayed 1–7 days with Impella/ECPELLA, and the mean Impella support days before surgery was 3.9 ± 2.5 days (Table 1). The changes in laboratory data before and after the Impella support are presented in Fig. 2 and Supplementary Material, Table S1. There were

Table 1: Preoperative profile of each patient

| Pt. No. | Age  | Sex | Diagnosis                          | STS-PROM | ECMO type | Impella type | Impella pump speed | Impella flow (l/min) | ECMO flow (l/min) | Cardiac index (l/min/m²) | Impella to surgery (days) |
|--------|------|-----|------------------------------------|----------|-----------|--------------|---------------------|---------------------|--------------------|--------------------------|---------------------------|
| 1      | 76   | M   | Ventricular septal rupture, post AMI | 26.9      | VA        | CP           | P6                  | 2                   | 4.5                | –                        | 6                         |
| 2      | 85   | F   | Ventricular septal rupture, post AMI | 45.1      | None      | CP           | P6                  | 2.2                 | –                  | –                        | 2                         |
| 3      | 73   | M   | Ventricular septal rupture, post AMI | 21.7      | VA        | CP           | P2                  | 1.5                 | 4.3                | –                        | 7                         |
| 4      | 71   | M   | Papillary muscle rupture, post AMI  | 24.9      | VA        | CP           | P9                  | 3.5                 | 3.5                | –                        | 6                         |
| 5      | 72   | M   | AMI                                | 17.4      | None      | CP           | P9                  | 3.7                 | –                  | 1.9                      | 1                         |
| 6      | 79   | M   | AMI                                | 24.5      | None      | CP           | P9                  | 3.7                 | –                  | 2.9                      | 4                         |
| 7      | 67   | M   | AMI                                | 15.6      | None      | CP           | P9                  | 3.7                 | –                  | 1.8                      | 1                         |
| Mean ± SD |     |     |                                   | 25.2 ± 9.7|           |               |                     | 2.9 ± 1.0           | 2.9 ± 1.0           | 1.9 ± 2.5                | 3.9 ± 2.5                 |

AMI: acute myocardial infarction; ECMO: extracorporeal membrane oxygenation, F: female; M: male; Pt. No.: patient number; SD: standard deviation; STS-PROM: Society of Thoracic Surgery-Predicted Risk of Mortality; VA: veno-arterial.

Figure 1: Intraoperative epiaortic echocardiogram showing (A) the pump portion of Impella and (B) catheter shaft of Impella.
significant decreases in lactate and aspartate aminotransferase levels. Serum creatinine and alanine aminotransferase level also decreased, although no statistically significant differences were observed.

Impella management during surgery

In the 3 patients who underwent coronary artery bypass grafting (Table 2, Pt. No. 5–7), aorta was not cross-clamped during the surgery and the position adjustment of the Impella was not required. An aortic cross-clamp was required in the other 4 patients during surgery (Table 2, Pt. No. 1–4). The aorta was efficiently cross-clamped enough to achieve rapid cardioplegic arrest even with the Impella cable inside the aorta in all these patients. After aortic declamping, the position adjustment of the Impella was very difficult in a patient who underwent repair of ventricular septal rupture (Pt. No. 2). An increase in the speed of the Impella pump resulted in frequent suction events. Therefore, adequate Impella support to wean off cardiopulmonary bypass was not obtained. The Impella was removed, and an intra-aortic balloon pump (IABP) was inserted. Cardiopulmonary bypass was weaned off with IABP support. In 1 patient who underwent ventricular septal rupture repair (Pt. No. 1) and 2 patients who underwent coronary artery bypass grafting (Pt. No. 6 and 7), the native cardiac function recovered enough to wean off the cardiopulmonary bypass, and the Impella was removed after weaning off the cardiopulmonary bypass under acceptable amount of

![Graphs showing changes in serum lactate, creatinine, aspartate aminotransferase, and alanine aminotransferase levels with Impella support.]

Figure 2: Changes in serum lactate (upper-left), creatinine (upper-right), aspartate aminotransferase (lower-left) and alanine aminotransferase (lower-right) levels by Impella support.

| Table 2: Operative procedures and outcomes |
|-----------------------------------------|
| Pt. No. | Procedure       | Aortic cross-clamp | Post-op Impella (days) | Red blood cell transfusion (ml) | Complications                                                                 | Outcome                  |
|---------|-----------------|---------------------|------------------------|---------------------------------|-------------------------------------------------------------------------------|--------------------------|
| 1       | VSR repair + CABG | Yes                 | 0                      | 1680                            | 1400 3080                                                                    | Alive                    |
| 2       | VSR repair      | Yes                 | 0                      | 0                               | 1400 1400                                                                    | Alive                    |
| 3       | VSR repair      | Yes                 | 8                      | 5600                            | 3920 9520                                                                    | Reexploration for bleeding, acute limb ischaemia Alive |
| 4       | MV replacement + CABG | Yes             | 11                     | 11 760                          | 5320 17 080                                                                  | Aortic dissection, re-exploration for bleeding, stroke Alive 11 POD |
| 5       | On-pump beating CABG | No                 | 18                     | 21 000                          | 4760 25 760                                                                  | Reexamination for bleeding Dead 60 POD |
| 6       | On-pump beating CABG | No                 | 0                      | 0                               | 2240 2240                                                                    | Alive                    |
| 7       | On-pump beating CABG | No                 | 0                      | 4480                            | 560 5040                                                                     | Alive                    |
| Mean ± SD | 5.6 ± 6.8     | 9169 ± 9133         |                        |                                 |                                                                                |                          |

CABG: coronary artery bypass grafting; LA: left atrium; MV: mitral valve; OP: operation; POD: postoperative days; Pt. No.: patient number; SD: standard deviation; VSR: ventricular septal rupture.
inotropic support (Pt. No. 1: dobutamine 3 μg/kg/min + dopamine 1 μg/kg/min, Pt. No. 6: dobutamine 3 μg/kg/min, and Pt. No. 7: dobutamine 6 μg/kg/min, tapered off during the surgery).

Adverse events

The postoperative outcomes are summarized in Table 2. All patients required a significant amount of blood transfusions. The mean amount of red blood cells transfused during the hospital stay was 9,169 ± 9,133 ml (Table 2). In 5 out of 7 patients (Pt. No. 1, 3, 4, 5 and 7), more transfusions were required outside the operating room than during the operation. Main bleeding points in these patients were cannulation sites of Impella (and ECMO). Reexploration for bleeding was required in 3 patients (Pt. No. 3, 4, and 5).

Acute limb ischaemia occurred in 1 patient. In patient No. 3, Impella was successfully weaned off on postoperative day 8. The right femoral artery, where the Impella was inserted through the sheath, was surgically cut down, and the Impella was pulled out together with the sheath. Immediately after the Impella was removed, the arterial pulse in the right leg disappeared. Thrombectomy was performed using a Fogarty catheter. Massive thrombi were removed, and the arterial pulse of the right leg was recovered.

Acute aortic dissection was encountered in Pt. No. 4; this patient had been a long-term steroid user due to pemphigoid (prednisolone 13 mg/day, 10 years). During reoperation for bleeding, a flap in the descending aorta was detected by transoesophageal echocardiography. An enhanced computed tomography (CT) scan was performed and revealed an acute Stanford type A aortic dissection. The entry site was located at the aortic cannulation site. There was no visceral malperfusion, and the primary radical operation was considered intolerable. ECMO was successfully weaned off with Impella support on postoperative day 10. However, the next day, a massive haemorrhagic stroke occurred, and the patient died.

Patient survival

Pt. No. 4 died of a haemorrhagic stroke on postoperative day 11. Pt. No. 5 died from heart failure and multiple organ failure on postoperative day 60. Patient survival was 85.7% at 30 days and 71.4% at 1 year (Fig. 3). As a historical control, the survival of consecutive 13 patients with cardiogenic shock who were bridged to heart surgery with ECMO before April 2018 at our institute was evaluated. Cumulative survival at 30 days and 1 year was 61.5% and 30.8%, respectively. Although the difference was not statistically significant (P = 0.0992) due to the small sample size, the survival of the patients who were bridged to surgery with Impella tended to be better compared to that of historical control patients who were bridged only with ECMO (Fig. 3).

DISCUSSIONS

In this study, we used Impella as a bridge to heart surgery in 7 patients with profound cardiogenic shock. Radical surgery was delayed by 1–7 (3.9 ± 2.5) days. With the stabilization of haemodynamics with Impella support, laboratory data including lactate and aspartate aminotransferase significantly decreased. Serum creatinine level also normalized during this period. Open-heart surgery was performed safely with the Impella device remaining in the heart. Thirty-day mortality was 14.3%, and the cumulative survival was 71.4% at 1 year. Although not statistically significant, the survival tended to be better than that of historical control in which only ECMO was used as a bridge to surgery.

Indications for Impella support were acute myocardial infarction and its mechanical complications in all the 7 patients in this cohort. When using Impella in patients with ventricular septal rupture after acute myocardial infarction, there is a theoretical risk of right-to-left shunt and critical deoxygenation because the Impella actively drains blood from the left ventricle [15]. Although it seems that this phenomenon does not occur in most of the cases [9–14, 16], frequent follow-up by echocardiogram...
during the Impella support and proper management of Impella flow to protect against right-to-left shunt is very important [15].

In patients with acute myocardial infarction requiring coronary artery bypass grafting (Pt. No. 5-7), we did the surgery under cardiopulmonary support and without aortic cross-clamping. Although ‘off-pump’ coronary artery bypass grafting only with Impella support may also be possible [21], Impella support insufficiency due to dislocation of the Impella may frequently occur when the heart is lifted during the operation, so we prefer to do it under cardiopulmonary bypass support.

'Surgical mode' of Impella

Impella is equipped with ‘surgical mode’, which allows the pump to stop without triggering a ‘pump stopped, retrograde flow’ caution alarm. The purge system works continuously during surgical mode to protect the motor. When cross-clamping the aorta, care must be taken not to clamp the Impella at the pump motor or blood outflow portion (Fig. 1). In this study, 4 out of 7 patients underwent aortic cross-clamping with Impella remaining in the heart. In all cases, the surgical mode was used. The aorta was efficiently cross-clamped enough to achieve rapid cardiopulmonary arrest even with the Impella cable inside the aorta. There were no adverse events related to pump stoppage, such as pump thrombosis or pump damage due to aortic cross-clamping.

Timing of surgery

In the American College of Cardiology Foundation/American Heart Association guidelines published in 2013, emergency surgical repair was recommended in patients with ventricular septal rupture after myocardial infarction [22]. However, the European Society of Cardiology guidelines published in 2017 state that delayed elective surgery can be considered for patients who respond well to aggressive heart failure therapy [23]. The new recommendation is based on the high mortality reported as the outcome of emergency surgery in patients with cardiogenic shock [1-3]. There has been accumulation of evidence that delayed surgery after stabilization of haemodynamics and improvement in end-organ function yield better outcomes compared to emergency surgery in cases with cardiogenic shock [1, 3-6].

To stabilize haemodynamics and improve end-organ perfusion in patients with cardiogenic shock refractory to medication, mechanical circulatory support is required. Furui et al. [4] used IABP to delay surgery in patients with ventricular septal rupture. They waited ~2 weeks after the onset of myocardial infarction. In their series, 20 patients required IABP support before surgery, 10 of them were suitable for elective surgery, whereas the other 10 patients required non-elective surgery even with IABP support. Their findings indicate that IABP support is not always effective enough to delay surgery in patients with ventricular septal rupture. Morimura and Tabata [6] also used IABP in 8 patients with cardiogenic shock due to ventricular septal rupture. In their study, ECMO was also used aggressively in addition to IABP (5 of 8 patients). Surgery was delayed for 1.9 (1.3-2.3) days after the diagnosis of ventricular septal rupture. During this period, biomarkers of end-organ perfusions, such as serum aspartate aminotransferase, alanine aminotransferase and lactate, improved significantly. La Torre et al. [16] used Impella as a bridge to surgery in 5 patients with ventricular septal rupture. In their study, the mean duration of Impella support was up to 14.4 ± 6 days. During this period, a significant improvement in organ function was observed, but 1 patient died of untreatable femoral artery bleeding following surgery, and the 30-day mortality rate was as high as 40%. Although mechanical circulatory support may improve haemodynamics and end-organ function in patients with cardiogenic shock, its long-term use may increase device-related complications. It is essential, but still very difficult to determine how long mechanical circulatory support should be continued before heart surgery in patients with cardiogenic shock. In the present study, the duration of Impella support before surgery was 3.9 ± 2.5 days and was much shorter than that of the study by La Torre et al.; the 30-day mortality was 14.3%.

Adverse events

Severe or life-threatening bleeding is a significant complication related to Impella support [16, 18, 24, 25]. Impella has been reported to induce acquired von Willebrand syndrome due to mechanical shear stress [26, 27]. Increased shear stress leads to excessive proteolysis of von Willebrand factor and loss of high molecular weight multimers, thus contributing to platelet dysfunction and increased bleeding. Flierl et al. reported that the loss of large multimers of von Willebrand factor was observed as early as 10.6 ± 10.8 h after the initiation of Impella support [26]. Early development of acquired von Willebrand disease contributes to an increased risk of perioperative bleeding complications [27]. Strong, continuous anticoagulation with purge solution is also associated with a high frequency of bleeding events and mortality [28]. In this study, all 7 patients required a significant amount of transfusion during the Impella support and perioperative period. The amount of transfusion was especially high in the 2 patients who died (Pt. No. 4 and 5) (Table 2). Moreover, 42.9% (3/7) of the patients (Pt. No. 3, 4 and 5) developed severe perioperative coagulopathy and required re-exploration for bleeding. One patient (Pt. No. 5) was supported with Impella only for 1 day preoperatively. One patient (Pt. No. 4) died from haemorrhagic stroke, and 1 patient (Pt. No. 5) died from multiple organ failure.
Peripheral vascular events are another well-known complication associated with Impella support [17, 24, 29]. Patel et al. [29] studied 31,263 patients who underwent Impella support in the USA and found that 13.5% of the patients had vascular complications, out of which 56% required surgical treatment. Acute limb thromboembolism and bleeding requiring transfusion accounted for 27.6% and 21.8% of all vascular complications, respectively [29]. We experienced 1 case (14.3%) with acute thromboembolism after the removal of the Impella (Pt. No. 3). As thrombus formation along the Impella shaft is sometimes observed on CT scans (Fig. 4), we speculate that this is the cause of embolism. It is essential to evaluate thrombus formation with an enhanced CT scan before pulling out the Impella, although it is sometimes difficult due to impaired renal function of the patient.

We also experienced acute aortic dissection in 1 patient (Pt. No. 4). Intraoperative aortic dissection is a rare but potentially catastrophic complication of cardiac surgery and is reported to occur in 0.35% of cases that use aortic cross-clamping [30]. Our patient was a long-term steroid user, and the entry of the aortic dissection was not located at the aortic cross-clamp site but at the aortic cannulation site. Therefore, we believe that this complication was not directly related to Impella support. However, adequate caution is required when cross-clamping the aorta with the Impella inside.

Limitations

There are several limitations to this study, including its retrospective nature. The sample size was small. A sample size of 7 makes it difficult to compare the results with those of other studies with larger sample sizes. This was a single-arm, non-comparative study. Although a randomized study is not realistic, a comparative study with a larger sample size and longer follow-up may be necessary to evaluate the effectiveness of this therapeutic strategy.

CONCLUSIONS

Impella support improved haemodynamics and end-organ function in patients with cardiogenic shock and was effective in bridging high-risk patients to surgery. This strategy may improve surgical outcomes in patients with cardiogenic shock. However, prolonged support with Impella may increase significant adverse events, and further investigation is required to determine the optimal duration of support before surgery.

SUPPLEMENTARY MATERIAL

Supplementary material is available at ICVTS online.

ACKNOWLEDGEMENT

We would like to thank Editage (www.editage.com) for English language editing.

Conflict of interest: none declared.

Data availability statement

All relevant data are within the manuscript and its Supporting Information files.

Author contributions

Shunsuke Saito: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing—original draft; Writing—review & editing. Ikuko Shibasaki: Data curation; Investigation. Taiki Matsuoka: Data curation; Investigation. Ken Niitsuma: Data curation; Investigation. Shotoaro Hirota: Data curation; Investigation. Yasuyuki Kanno: Data curation; Investigation. Yuta Kanazawa: Data curation; Investigation. Masahiro Tazuka: Data curation; Investigation. Yusuke Takei: Data curation; Investigation. Go Tsuchiya: Data curation; Investigation. Taisuke Konishi: Data curation; Investigation. Koji Ogata: Data curation; Investigation. Hirotugu Fukuda: Conceptualization; Supervision; Writing—review & editing.

Reviewer information

Interactive CardioVascular and Thoracic Surgery thanks Themistokles Chamogeorgakis and the other, anonymous reviewer(s) for their contribution to the peer review process of this article.

REFERENCES

[1] Menov N, Webb JG, Hillis LD, Sleeper LA, Abboud R, Dzavik V et al. Outcome and profile of ventricular septal rupture with cardiogenic shock after myocardial infarction: a report from the SHOCK trial registry. SHould we emergently revascularize Occluded Coronaries in cardiogenic shock? J Am Coll Cardiol 2000;36:1110–6.
[2] Rob D, Spurda R, Lindner J, Rohn V, Kunstr J, Balik M et al. A rationale for early extracorporeal membrane oxygenation in patients with postinfarction ventricular septal rupture complicated by cardiogenic shock. Eur J Heart Fail 2017;19: 97–103.
[3] Coskun KO, Coskun ST, Popov AF, Hinz J, Schmitto JD, Bockhorst K et al. Experiences with surgical treatment of ventricle septal defect as a post infarction complication. J Cardiothorac Surg 2009;4:3.
[4] Furui M, Yoshida T, Kaki B, Uchino G, Nishihara H. Strategy of delayed surgery for ventricular septal perforation after acute myocardial infarction. J Cardiothorac Surg 2018;71:488–93.
[5] Liebelt JJ, Yang Y, DeRose JJ, Taub CC. Ventricular septal rupture complicating acute myocardial infarction in the modern era with mechanical circulatory support: a single center observational study. Am J Cardiovasc Dis 2016;6:10–6.
[6] Morimura H, Tabata M. Delayed surgery after mechanical circulatory support for ventricular septal rupture with cardiogenic shock. Interact CardioVasc Thorac Surg 2020;31:868–73.
[7] Rios SA, Bravo CA, Weinreich M, Olmedo W, Villablanca P, Villela MA et al. Meta-analysis and trial sequential analysis comparing percutaneous ventricular assist devices versus intra-aortic balloon pump during high-risk percutaneous coronary intervention or cardiogenic shock. Am J Cardiol 2018;122:1330–8.
[8] Chung JS, Emerson D, Ramzy D, Akhmerov A, Megna D, Espin F et al. A new paradigm in mechanical circulatory support: 100-patient experience. Ann Thorac Surg 2020;109:1370–7.
[9] Patane F, Centenfanti P, Zingarelli E, Sansone F, La Torre M. Potential role of the Impella recover left ventricular assist device in the management of postinfarct ventricular septal defect. J Thorac Cardiovasc Surg 2009; 137:1288–9.
[10] Ancona MB, Regazzoli D, Mangieri A, Monaco F, De Bonis M, Latib A. Post-infarct ventricular septal rupture: early Impella implantation to delay surgery and reduce surgical risk. Cardiovasc Interv Ther 2017;32: 381–5.
[11] Iida M, Uchiyama M, Shimokawa T. A successful case of percutaneous left ventricular assist device “Impella” to postmyocardial infarction ventricular septal perforation in Japan. Artif Organs 2019;43:806–7.
Nakamura M, Imamura T, Fukui T, Ueno Y, Ueno H, Yokoyama S et al. Impella support as a bridge to scheduled surgical repair of ventricular septal rupture. J Artif Organs 2020;23:278–82.

Cohen J, Montgomery RA, Zmaili MA, Rampersad P, Menon V, Tong MZ et al. Post-myocardial infarction ventricular septal rupture bridged to heartmate 3 with an Impella 5.5. Ann Thorac Surg 2021;112:e161–e163.

Briani M, Torracca L, Crescenzi G, Barbone A. Impella 5.0 support before, during, and after surgical ventriculoplasty following acute myocardial infarction in the COVID-19 era: a case report. Eur Heart J Case Rep 2021;5:ytab037.

Hirao A, Saku K, Nishikawa T, Sunagawa K. A case report of unexpected right-to-left shunt undermechanical support for post-infarction ventricular septal defect: evaluation with haemodynamic simulator. Eur Heart J Case Rep 2021;5:1–6.

La Torre MW, Centofanti P, Attisani M, Patané F, Rinaldi M. Posterior ventricular septal defect in presence of cardiogenic shock: early implantation of the Impella recover LP 5.0 as a bridge to surgery. Tex Heart Inst J 2011;38:42–9.

Reynolds HR, Hochman JS. Cardiogenic shock: current concepts and improving outcomes. Circulation 2008;117:686–97.

Kanda Y. Investigation of the freely available easy-to-use software ‘EZr’ for medical statistics. Bone Marrow Transplant 2013;48:452–8.

Meani P, Lorusso R, Pappalardo F. ECPella: concept, physiology and clinical applications. J Cardiothorac Vasc Anesth 2022;36:557–66. https://doi.org/10.1053/j.jvca.2021.01.056.

Schrage B, Becher PM, Bernhardt A, Bezerra H, Blankenberg S, Brunner S et al. Left ventricular unloading is associated with lower mortality in patients with cardiogenic shock treated with venaovenous extracorporeal membrane oxygenation: results from an international, multicenter cohort study. Circulation 2020;142:2095–106.

Upadhyaya VD, Campbell S, Douedi S, Patel I, Asgarian KT, Saybolt MD. Use of Impella CP device in off-pump coronary artery bypass graft surgery. Int Heart J 2021;62:175–7.

O’Gara PT, Kushner FG, Ascheim DD, Casey DE Jr, Chung MK, de Lemos JA et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. Circulation 2013;127:e362–425.

Ibanez B, James S, Agewall S, Antunes MJ, Bucciarelli-Ducci C, Bueno H et al. 2017 ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation: the task force for the management of acute myocardial infarction in patients presenting with ST-segment elevation of the European Society of Cardiology (ESC). Eur Heart J 2018;39:119–77.

Schrage B, Ibrahim K, Loehn T, Werner N, Sinning JM, Pappalardo F et al. Impella support for acute myocardial infarction complicated by cardiogenic shock. Circulation 2019;139:1249–58.

Ouweneel DM, Eriksen E, Sjauw KD, van Dongen IM, Hirsch A, Packer EJ et al. Percutaneous mechanical circulatory support versus intra-aortic balloon pump in cardiogenic shock after acute myocardial infarction. J Am Coll Card 2017;69:278–87.

Flierl U, Tongers J, Berliner D, Sieweke JT, Zauner F, Wingert C et al. Acquired von Willebrand syndrome in cardiogenic shock patients on mechanical circulatory microaxial pump support. PLoS One 2017;12:e0183193.

Davis ME, Haglund NA, Tricarico NM, Keebler ME, Maltais S. Development of acquired von Willebrand syndrome during short-term micro axial pump support: implications for bleeding in a patient bridged to a long-term continuous-flow left ventricular assist device. ASAIO J 2014;60:355–7.

Nakamura M, Imamura T, Ueno H, Hori M, Ushijima R, Kinugawa K. Impact of the whole activated clotting time during Impella support on short-term prognosis. J Artif Organs 2021;25:1–5.

Patel N, Sharma A, Dalia T, Rali A, Earnest M, Tadros P et al. Vascular complications associated with percutaneous left ventricular assist device placement: a 10-year US perspective. Catheter Cardiovasc Interv 2020;95:2097–110.

Murphy DA, Craver JM, Jones EL, Bone DK, Guyton RA, Hatcher CR Jr., Recognition and management of ascending aortic dissection complicating cardiac surgical operations. J Thorac Cardiovasc Surg 1983;85:247–56.