UNIVERSITÄT AUGSBURG
Universitätsbibliothek

OPEN ACCESS
OPUS AUGSBURG

Temporary circulatory support with surgically implanted microaxial pumps in postcardiotomy cardiogenic shock following coronary artery bypass surgery

Wiebke Sommer, Rawa Arif, Jamila Kremer, Sameer Al Maisary, Markus Verch, Ursula Tochtermann, Matthias Karck, Anna L. Meyer, Gregor Warnecke

Angaben zur Veröffentlichung / Publication details:

Sommer, Wiebke, Rawa Arif, Jamila Kremer, Sameer Al Maisary, Markus Verch, Ursula Tochtermann, Matthias Karck, Anna L. Meyer, and Gregor Warnecke. 2023. "Temporary circulatory support with surgically implanted microaxial pumps in postcardiotomy cardiogenic shock following coronary artery bypass surgery." *JTCVS Open* 15: 252–60. https://doi.org/10.1016/j.xjon.2023.06.015.

Nutzungsbedingungen / Terms of use:

CC BY-NC-ND 4.0

Dieses Dokument wird unter folgenden Bedingungen zur Verfügung gestellt: / This document is made available under these conditions:
CC-BY-NC-ND 4.0: Creative Commons: Namensnennung - Nicht kommerziell - Keine Bearbeitung
Weitere Informationen finden Sie unter: / For more information see:
https://creativecommons.org/licenses/by-nc-nd/4.0/deed.de

Temporary circulatory support with surgically implanted microaxial pumps in postcardiotomy cardiogenic shock following coronary artery bypass surgery

Check for updates

Wiebke Sommer, MD, Rawa Arif, MD, Jamila Kremer, MD, Sameer Al Maisary, MD, Markus Verch, MD, Ursula Tochtermann, MD, Matthias Karck, MD, Anna L. Meyer, MD, and Gregor Warnecke, MD

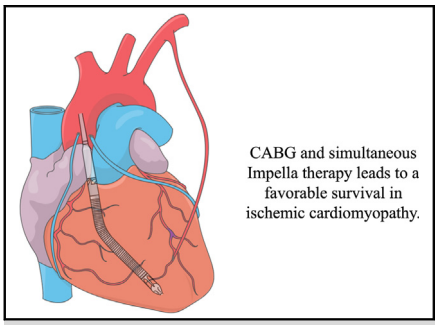
ABSTRACT

Objectives: Patients with ischemic cardiomyopathy undergoing coronary artery bypass grafting (CABG) surgery may develop postcardiotomy cardiogenic shock. In these cases, implantation of an Impella 5.0 or 5.5 microaxial pump offers full hemodynamic support while simultaneously unloading of the left ventricle.

Methods: Preoperative, perioperative, and postoperative data of all patients receiving postoperative support with an Impella 5.0 or 5.5 after CABG surgery between September 2017 and October 2022 were retrospectively collected. Cohort built-up was performed according to the timing of Impella implantation, either simultaneous during CABG surgery or delayed.

Results: A total of n = 42 patients received postoperative Impella support, of whom 27 patients underwent simultaneous Impella implantation during CABG surgery and 15 patients underwent delayed Impella therapy. Preoperative left ventricular ejection fraction was similarly low in both groups (26.7 ± 0.7% vs 24.8 ± 11.3%; $P = .32$). In the delayed cohort, Impella implantation was performed after a median of 1 (1; 2) days after CABG surgery. Survival after 30 days (75.6% vs 47.6%, $P = .04$) and 1 year (69.4% vs 29.8%, $P = .03$) was better in the cohort receiving simultaneous Impella implantation.

Conclusions: The combined advantages of hemodynamic support and LV unloading with microaxial pumps may lead to a favorable survival in patients with left ventricular failure following CABG surgery. Early implantation during the initial surgery shows a trend toward a more favorable survival as compared with patients receiving delayed support. (JTCVS Open 2023;15:252-60)



CABG and simultaneous Impella therapy shows superior survival in ischemic cardiomyopathy.

CENTRAL MESSAGE

Early simultaneous CABG and Impella implantation led to more favorable survival probably due to the combined advantages of hemodynamic support and LV unloading.

PERSPECTIVE

Treatment of postcardiotomy shock following CABG surgery with surgically implantable microaxial pumps combines hemodynamic support while simultaneously unloading the left ventricle. In this analysis, survival in patients with ischemic cardiomyopathy was favorable when implementation of the Impella support was initiated early during CABG surgery as compared with delayed Impella implantation.

Postcardiotomy cardiogenic shock represents a major complication, entailing the inability to wean a patient off cardiopulmonary bypass (CPB) following cardiac surgery.[1] Given the increasing morbidity of patients being accepted for cardiac surgery as well as the increasing number of procedures being performed in urgent patients, the need for postoperative extracorporeal support for left ventricular (LV) failure represents a daily clinical dilemma.[2] With

From the Department of Cardiac Surgery, University of Heidelberg, Heidelberg, Germany.
Drs Sommer and Arif are first authors.
Drs Meyer and Warnecke are last authors.
Received for publication Jan 10, 2023; revisions received June 14, 2023; accepted for publication June 20, 2023; available ahead of print July 28, 2023.
Address for reprints: Wiebke Sommer, MD, Department of Cardiac Surgery, University of Heidelberg, Im Neuenheimer Feld 420, 69120 Heidelberg, Germany (E-mail: wiebke.sommer@med.uni-heidelberg.de).

2666-2736
Copyright © 2023 The Author(s). Published by Elsevier Inc. on behalf of The American Association for Thoracic Surgery. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
https://doi.org/10.1016/j.xjon.2023.06.015

Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CPB = cardiopulmonary bypass
ECMO = extracorporeal membrane oxygenation
ICU = intensive care unit
LV = left ventricle/ventricular
VA = venoarterial
VIS = vasoactive–inotropic score

regard to published postoperative survival, the ideal setting for postcardiotomy extracorporeal support remains to be identified.[3] Venoarterial (VA) extracorporeal membrane oxygenation (ECMO) implanted either centrally or peripherally for either LV, right ventricular, or biventricular failure following cardiac surgery shows an overall survival not exceeding 25% to 42% in recent literature.[1,3-10]

The lack of cardiac recovery in a sizeable proportion of patients on VA ECMO following postcardiotomy failure may be due to the absence of active LV venting and increased cardiac afterload. Impella devices being placed in the LV with active drainage of the LV result in decreased wall tension of the ventricle as well as attenuating LV afterload. Use of surgically implanted Impella devices (5.0 or 5.5) represents a prospect to combine full left-sided hemodynamic support while unloading the LV, thus facilitating LV recovery.[11,12] The aim of this retrospective analysis was to analyze the potential of Impella 5.0 and 5.5 devices in patients with postcardiotomy failure following CABG surgery.

METHODS

All patients receiving Impella 5.0 or 5.5 support after coronary artery bypass grafting (CABG) surgery between September 2017 and October 2022, either in the same procedure or delayed after the CABG surgery due to low cardiac output, were included into the retrospective data analysis. Preoperative, perioperative, as well as postoperative patient characteristics were retrospectively collected and survival up to 1 year after cardiac surgery was obtained. Urgency of CABG surgery was defined as either elective, urgent (within 3 days after CABG indication), or emergency surgery, which was performed immediately after indication.

The primary end point of this analysis was in-hospital as well as 1-year-survival. Secondary end points were Impella-associated complications, specifically cerebrovascular events during the course of Impella treatment, as well as severe bleeding events, defined by requiring >2 red packed cells per 24 hours. Outcome of patients who received simultaneous Impella implantation within the initial surgery was compared with patients receiving delayed Impella implantation during the postoperative course. The local institutional ethical review board approved the analysis (S-759/2021; University of Heidelberg, date of approval: November 2021).

Definition of Cardiogenic Shock

Cardiogenic shock before initial CABG surgery as well as postcardiotomy cardiogenic shock leading to Impella implantation were defined following current American Heart Association guidelines as blood pressure <90 mm Hg or need of vasopressors to maintain a blood pressure >90 mm Hg and at least 1 sign of hypoperfusion (eg, confusion, cold extremities, oliguria, increased serum lactate, increased creatinine, increased liver enzymes, metabolic acidosis).[13] The decision for the implantation of an extracorporeal support device as well as the decision of which device (eg, Impella, ECMO) was made by the surgeon in charge.

Vasoactive–Inotropic Score (VIS)

The VIS was retrospectively calculated in both groups before Impella implantation. In the simultaneous group, the score was calculated using the catecholamine support required when CPB was reduced and weaning off CPB failed, in the delayed group, VIS was calculated immediately postoperatively upon arrival on intensive care unit (ICU) and additionally immediately before delayed Impella implantation. The VIS was calculated using a modified score by Nguyen and colleagues[14]:

$$\begin{aligned}\text{VIS} = {} & \text{dopamine dose } (\mu g / kg / min) \\ & + \text{dobutamine dose } (\mu g / kg / min) + 100 \\ & \times \text{epinephrine dose } (\mu g / kg / min) + 10 \\ & \times \text{milrinone dose } (\mu g / kg / min) + 10.000 \\ & \times \text{vasopressin dose } (U / kg / min) + 100 \\ & \times \text{norepinephrine dose } (\mu g / kg / min) + 10 \\ & \times \text{phenylepinephrine dose } (\mu g / kg / min)\end{aligned}$$

Impella Implantation Technique and ICU Standard Treatment Regimen

Impella was implanted intraoperatively within the primary cardiac procedure or secondarily immediately following the decision to support a patient with delayed Impella therapy. As described previously,[11,15,16] Impella 5.0 and 5.5 devices were implanted using a right or left subclavian access. In brief, in general anesthesia, a lateral incision underneath the clavicle was performed and the subclavian artery was dissected. A 10-mm prosthesis was anastomosed to the artery and the Impella device was inserted through a sheath after placement of the corresponding wire in the LV using fluoroscopy. Correct placement of the Impella device was monitored using transesophageal echocardiography. Anticoagulation during the insertion procedure was performed using heparin, aiming for an activated clotting time >250 seconds; maintenance anticoagulation on ICU aimed for an activated clotting time of 160 to 180 seconds. In patients showing postoperative bleeding, heparin treatment was reduced or even ceased for a maximum of 24 hours postoperatively.

The pharmacologic strategy upon arrival on ICU was weaning of vasopressor support while maintaining low-dose inotropic support in most cases, especially when biventricular impairment was noted. Central venous saturation (>70%) as well as serum lactate monitoring were continuously performed for hemodynamic monitoring.

Regular echocardiography examinations of left and right ventricle ejection fraction, local wall motion abnormalities, as well as valve abnormalities were assessed. Early weaning off mechanical ventilation was intended in all patients, and mobilization of the patient in the chair with ongoing Impella support was performed whenever possible.

Weaning of Impella Support

Following hemodynamic stabilization and weaning of vasopressor medication as well as signs of cardiac recovery in echocardiography,

weaning off extracorporeal support was started. Step-wise reduction of the Impella device was performed over multiple days while closely monitoring central venous saturation, lactate, and vasopressor demand as well as LV function on echocardiography. Echocardiographic pa1rameters that were monitored on a daily basis included LV ejection fraction as well as LV end-diastolic diameter. Weaning was suspended and deferred when the patient required increasing doses of vasoactive agents (eg, norepinephrine), showed continuously low central venous saturation (<60%) or increasing serum lactate levels. Similarly, weaning was postponed in case of new signs for end-organ impairment (eg, increase of transaminases). When all parameters indicating a sufficient hemodynamic situation were stable while continuously reducing the Impella support, explantation of the device was performed typically using only local anesthesia infiltration in nonintubated patients.

Statistical Analysis

Data were collected and analyzed retrospectively. Categorical variables were summarized as frequencies and percentages. For comparison of continuous as well as categorical values, nonparametric testing was performed using Mann–Whitney *U*-tests. Continuous variables were described as mean ± standard deviation or median and interquartile ranges as appropriate. Survival was analyzed using log-rank testing. All statistical analyses were performed using GraphPad Prism 9.0 for MacOs (Apple).

RESULTS

Preoperative Patient Characteristics

A total of 42 patients were included into the retrospective analysis qualifying for postcardiotomy low cardiac output syndrome following CABG surgery with postoperative Impella 5.0 or 5.5 treatment. During the same time, a total of 2741 solitary CABG procedures were performed in our center; the proportion of patients requiring hemodynamic support with a microaxial pump was therefore 1.53%. Simultaneous Impella implantation within the initial surgery was performed in 27 patients, whereas 15 patients received a delayed Impella implantation. Median follow-up in the simultaneous group was 166 (median; interquartile range) (25; 215) days and 22 (6; 185) days in the delayed group.

Median age of the cohorts was similar (72.6 [63.9; 76.2] years vs 70.8 [67; 75] years; $P = .71$), and the majority of patients were male (81.5% vs 93.3%; $P = .39$). All patients presented with coronary artery disease.

Cardiovascular risk factors including arterial hypertension (81.5% vs 86.7%; $P = .64$), history of smoking

TABLE 1. Patient characteristics

Characteristics	Simultaneous Impella implantation (n = 27)	Delayed Impella implantation (n = 15)	*P* value
Age, y, median; IQR	72.6; 63.9-76.2	70.8; 67-75.6	.71
Female, n; %	5; 18.5	1; 6.7	.39
White, n; %	27; 100	15; 100	>.99
BMI, mean ± SD	27.2 ± 4.9	24.1 ± 3.0	.05
Familiar predisposition for cardiac disease, n; %	3; 11.1	2; 13.3	>.99
Diabetes mellitus, n; %	16; 59.2	7; 46.7	.52
Arterial hypertension, n; %	22; 81.5	13; 86.7	.64
Smoking, n; %	18; 66.7	7; 46.7	.48
Hyperlipidemia, n; %	22; 81.5	8; 53.3	.19
Preoperative mechanical ventilation, n; %	3; 11.1	1; 6.7	>.99
Acute myocardial infarction, n; %	24; 88.9	10; 66.7	.12
Preoperative CK, U/L, mean ± SD	551.7 ± 811.4	310.7 ± 499.1	.14
Preoperative CK-MB, U/L, mean ± SD	75.5 ± 96.4	49.8 ± 63.1	.88
Preoperative LVEF, %, mean ± SD	26.7 ± 9.4	24.8 ± 11.3	.32
Preoperative CPR, n; %	2; 7.4	–	.53
Preoperative cardiogenic shock, n; %*	6; 22.2	1; 6.7	.39
Preoperative pharmaceutical catecholamine support, n; %	9; 33.3	1; 6.7	.07
NYHA I, n; %	–	–	–
NYHA II, n; %	–	1; 6.7	.36
NYHA III, n; %	13; 48.1	10; 66.7	.34
NYHA IV, n; %	14; 51.9	4; 26.7	.19

*Cardiogenic shock definition: RR < 90 mm Hg or need of vasopressors to maintain RR > 90 mm Hg and sign at least 1 sign of hypoperfusion (confusion, cold extremities, oliguria, increased serum lactate, increased creatinine, increased liver enzymes, metabolic acidosis)[13]; Mann–Whitney *U* test. *IQR*, Interquartile range; *BMI*, body mass index; *SD*, standard deviation; *CK*, creatine kinase; *CK-MB*, creatine kinase-MB; *LVEF*, left ventricular ejection fraction; *CPR*, cardiopulmonary resuscitation; *NYHA*, New York Heart Association; *RR*, blood pressure.

(66.7% vs 46.7%; $P = .48$), hyperlipidemia (81.5% vs 53.3%; $P = .19$), diabetes (59.2% vs 46.7%; $P = .52$), and familiar predisposition for cardiac diseases (11.1% vs 13.3%; $P > .99$) were similarly distributed in both cohorts (Table 1).

The majority of patients in both cohorts presented with advanced heart failure categorizing in New York Heart Association class III (48.1% vs 66.7%; $P = .34$) or class IV (51.9% vs 26.7%; $P = .19$). In the simultaneous group, 6 patients were in cardiogenic shock before CABG surgery, whereas only 1 patient in the delayed group showed signs of cardiogenic shock preoperatively (22.2% vs 6.7%; $P = .39$). Similarly, preoperative need for pharmaceutical catecholamine support was necessary in 9 patients in the simultaneous group and in 1 patient of the delayed group (33.3% vs 6.7%; $P = .07$). Most patients in both cohorts presented with an acute myocardial infarction (88.9% vs 66.7%; $P = .12$) with accompanying elevated cardiac enzymes preoperatively (creatine kinase-MB 75.5 ± 96.4 U/L vs 49.8 ± 63.1 U/L ; $P = .88$). Mean preoperative LV ejection fraction was not different in both cohorts (26.7 ± 9.4% vs 24.8 ± 11.3%; $P = .32$) (Table 1).

Peri- and Postoperative Patient Characteristics

The majority of surgeries were classified as emergency interventions in both groups (51.9% vs 60.0%; $P = .75$) and in 4 patients in the simultaneous group, surgery was performed as a last-resort option. Urgent surgery was performed in 8 patients in the simultaneous group and in 2 patients of the delayed group ($P = .29$). Elective surgery occurred more often in the delayed group (3.7% vs 26.7%; $P = .04$) (Table 2).

The majority of patients underwent only CABG in both groups (81.5% vs 73.3%; $P = .70$). Three patients in the simultaneous group underwent combined CABG and mitral valve surgery. Other surgeries included combined CABG and aortic valve replacement (3.7% vs 20.0%; $P = .12$); 1 patient in the delayed group underwent combined CABG and tricuspid valve reconstruction. One patient in the simultaneous group underwent redo CABG surgery. Mean time on CPB was similar in both groups (167.7 ± 58.3 minutes vs 143.5 ± 63.5 minutes; $P = .14$). Similarly, mean aortic crossclamp time was not different in both groups (59.7 ± 26.2 minutes vs 73.9 ± 28.4 minutes; $P = .19$). Total duration of surgery was longer in the simultaneous group (374.2 ± 78.3 vs 295.4 ± 72.9; $P = .0008$), most likely due to the additional time for the Impella device implantation (Table 2).

In patients who underwent delayed Impella implantation, implantation was performed after a median of 1 (1; 2) days after open heart surgery. In the simultaneous group, the calculated vasoactive inotropic score at the end of CABG surgery when CPB weaning was attempted and subsequently failed was 37.3 points. In contrast, the delayed group showed a VIS of 23.8 points immediately after CABG surgery upon arrival to the ICU. In this cohort, the calculated VIS increased to 36.9 immediately before delayed Impella implantation (Figure 1).

TABLE 2. Operative data

	Simultaneous Impella implantation (n = 27)	Delayed Impella implantation (n = 15)	*P* value
Urgency of surgery, n; %			
Elective	1; 3.7	4; 26.7	.04
Urgent	8; 29.6	2; 13.3	.29
Emergency	14; 51.9	9; 60.0	.75
Last resort	4; 14.8	–	.28
Surgery, n; %			
CABG	22; 81.5	11; 73.3	.70
CABG + MVR	3; 11.1	–	.29
Re-do CABG	1; 3.7	–	>.99
CABG + AVR	1; 3.7	3; 20.0	.12
CABG + TVR	–	1; 6.7	.36
Cardiopulmonary bypass, min, mean ± SD	167.7 ± 58.3	143.5 ± 63.5	.14
Aortic crossclamp time, min, mean ± SD	59.7 ± 26.2	73.9 ± 28.4	.19
Duration of CABG surgery, min, mean ± SD	374.2 ± 78.3	295.4 ± 72.9	.0008
Delay of Impella implantation after cardiac surgery, d (median; IQR)	–	1 (1; 2)	–

Mann–Whitney *U* test. *CABG*, Coronary artery bypass grafting; *MVR*, mitral valve replacement; *AVR*, aortic valve replacement; *TVR*, tricuspid valve repair; *SD*, standard deviation; *IQR*, interquartile range.

In the simultaneous group, 9 patients received an Impella 5.0 and 18 patients an Impella 5.5. device. In the delayed group, 6 patients received an Impella 5.0 and the remaining 9 patients underwent Impella 5.5 implantation.

Duration of postoperative mechanical ventilation was similar in both groups after surgery (median 3.7 [0.8; 14.9] days vs 9.9 [3.9; 17.7] days; $P = .09$), and median time on ICU also did not differ between both cohorts (median 13 [8; 23] days vs 17 [6; 26] days; $P = .92$). Similarly, median total hospital stay was not different in both groups (20 [13; 24] days vs 18 [8; 28] days; $P = .96$). Renal-replacement therapy for acute renal failure was necessary in 12 patients of the simultaneous group and 8 patients in the delayed group ($P = .75$). Tracheostomy for weaning off mechanical ventilation was performed in 7 patients of the simultaneous group and in 5 patients of the delayed Impella group ($P = .73$). Mobilization with ongoing Impella support at least into the chair was feasible in 66.7% (n = 18) of the patient sin the simultaneous group and in 53.3% (n = 8) of the patients in the delayed cohort.

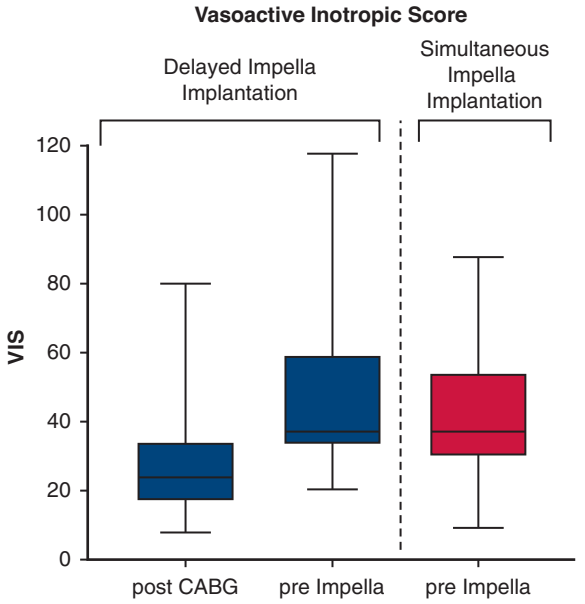


FIGURE 1. VIS. Patients undergoing delayed Impella implantation presented with a median VIS of 23.8 upon arrival on ICU immediately after CABG surgery. The score increased subsequently to a median VIS of 36.9 immediately before Impella implantation. In the simultaneous group, the retrospectively calculated VIS was 37.3 in the OR when CPB was reduced and failed to wean prior to Impella implantation. *Boxes* show lower and upper quartiles, *whiskers* represent minimum and maximum values. *Lines* represent median values. *VIS*, Vasoactive–inotropic score; *CABG*, coronary artery bypass grafting.

Resternotomy for bleeding was necessary in 6 patients in the simultaneous group, and 1 patient in the delayed group required surgical revision for bleeding (22.2% vs 6.7%; $P = .39$). Severe neurologic complications occurred in 3 patients in the simultaneous group and in 1 patient in the

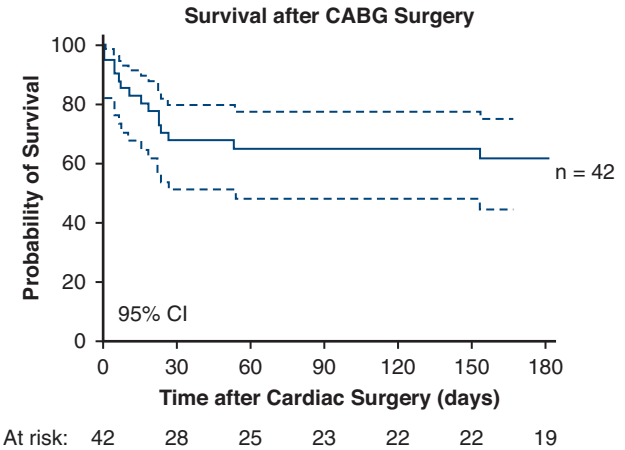


FIGURE 2. Survival after CABG surgery. Kaplan–Meier analysis of all patients (n = 42) requiring temporary mechanical support with an Impella microaxial pump following CABG surgery for ischemic cardiomyopathy. Shown are 95% confidence intervals (*error bars*). *CABG*, Coronary artery bypass grafting.

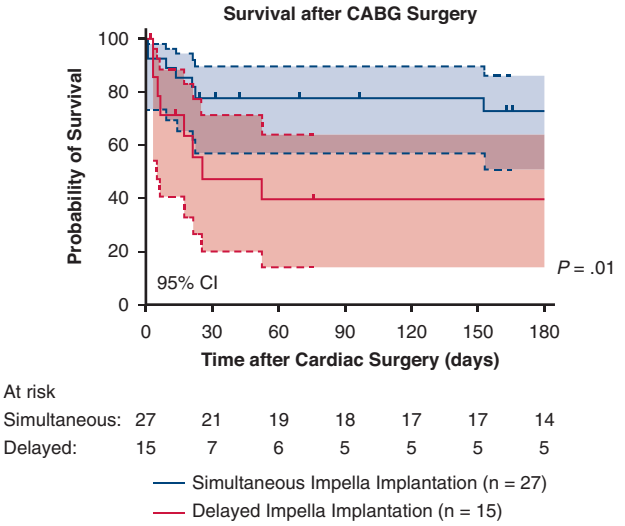


FIGURE 3. Survival after CABG surgery. Kaplan–Meier analysis of patients who received either simultaneous (n = 27) or delayed (n = 15) hemodynamic support with an Impella 5.0 or 5.5 device following CABG surgery in ischemic cardiomyopathy. The cohort undergoing early simultaneous Impella implantation shows a significantly better survival ($P = .03$) as compared with patients receiving delayed support. Censored events per group: delayed = 2, simultaneous = 4. Shown are 95% confidence intervals (*error bars*). *CABG*, Coronary artery bypass grafting.

delayed group (11.1% vs 6.7%; $P \geq .99$). Complications included signs of a thromboembolic stroke with hemiparesis following Impella explantation and simultaneous permanent assist device implantation in 1 patient, 1 patient showed acute vision defects with thromboembolic strokes on the computed tomography scan, and another patient presented with subacute drop foot syndrome, which was most likely not related to the microaxial pump therapy. The patient in the delayed group with a neurologic complication suffered from a brachial plexus lesion following Impella implantation with residual weakness of the right arm.

Three patients in the simultaneous group and 1 patient in the delayed group did not show sufficient cardiac recovery and therefore weaning off the temporary assist device in the absence of end-organ dysfunction failed. These patients ultimately underwent permanent assist device (HeartMate 3; Abbott) implantation.

Survival

Following cardiac surgery, overall 30-day survival of the cohort was 67.8% and 12-month survival was 58.1% in the entire cohort (Figure 2). Subanalysis of patients receiving simultaneous versus delayed Impella implantation following cardiac surgery showed a more favorable survival when receiving simultaneous hemodynamic support (30-day survival 77.8% vs 47.6%) (Figure 3). In-hospital survival was 33.3% in the delayed group and 70.4% in the simultaneous group (Table 3). Causes of death in the

TABLE 3. Postoperative characteristics

	Simultaneous Impella implantation (n = 27)	Delayed Impella implantation (n = 15)	*P* value
ICU stay, d (median; IQR)	13 (8; 23)	17 (6; 26)	.92
Mechanical ventilation, d (median; IQR)	3.7 (0.8; 14.9)	9.9 (3.9; 17.7)	.09
Total hospital stay, d (median; IQR)	20 (13; 24)	18 (8; 28)	.96
Renal-replacement therapy, n; %	12; 44.4	8; 53.3	.75
Bilirubin, max, mg/dL, mean ± SD	6.3 ± 7.6	8.3 ± 5.3	.02
Tracheostomy, n; %	7; 25.9	5; 33.3	.73
Re-sternotomy for bleeding, n; %	6; 22.2	1; 6.7	.39
Cerebrovascular event	3; 11.1	1; 6.7	>.99
Duration of Impella support, d (median; IQR)	9 (6; 16)	14 (5; 16)	.66
30-d survival, %	77.8	47.6	.04
6-mo survival, %	72.9	39.7	.06
1-y survival, %	72.9	29.8	.03

Mann–Whitney *U* test for categorical and continuous values, log-rank test for survival analysis. *ICU*, Intensive care unit; *IQR*, interquartile range; *SD*, standard deviation.

simultaneous group were sepsis (n = 5) and multiorgan failure (n = 3). One additional patient died due to coronavirus disease 2019 following discharge. In the delayed group, causes of death included multiorgan failure (n = 9) and malignant arrythmias (n = 1).

Failure to wean off temporary left heart assistance due to contraindications for permanent devices led to the death of patient in both cohorts. In the simultaneous group, 14.8% (n = 4) patients died while being on Impella support. In the delayed group, 46.7% (n = 7) patients died during ongoing support.

DISCUSSION

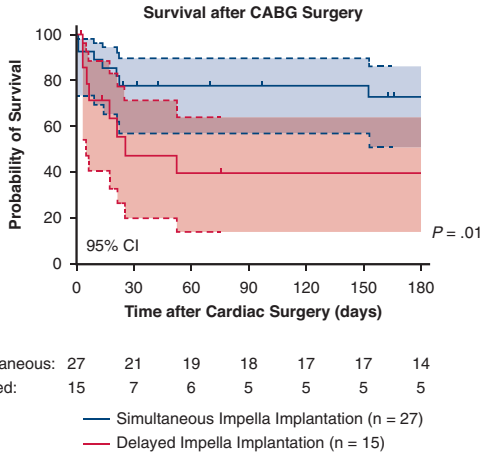
With this single-center experience, we were able to demonstrate a favorable postoperative survival in patients with postcardiotomy heart failure who received simultaneous Impella support within the initial CABG surgery. Patients who received temporary LV assist device therapy delayed after CABG surgery showed an inferior survival, underlining the importance of early decision-making in these hemodynamically critical patients. The calculated vasoactive inotropic score, which has previously been validated as a predictive score for morbidity and mortality in pediatric and adult cardiac surgical patients,[17,18] reflects in the majority of patients in the simultaneous cohort the decision-making process for an early Impella implantation. However, VIS values in the delayed group show that some patients in this group may have required earlier extracorporeal support, reflecting a learning process within our center. Hemodynamic support with a surgically implanted Impella device as a bridge to recovery or permanent assist device implantation generates full left-sided cardiac output while actively unloading the LV.[19] Despite unfavorable preoperative characteristics in our cohort with >60% of the patients undergoing emergency cardiac surgery or even surgery as a last resort option and the majority of patients having an acute myocardial infarction preoperatively, these results highlight the advantages of this left-sided cardiac support setting. Postcardiotomy failure typically occurs in patients with either preoperative acute or chronic left heart impairment or in patients with intraoperative myocardial injury due to inadequate cardioplegia and represents a clinical dilemma with unfavorable outcome.[20] Our cohorts reflect these risk factors, showing severely reduced LV ejection fraction preoperatively.

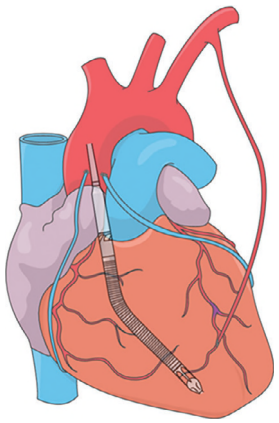
The current consensus for postcardiotomy extracorporeal circulatory support primarily focuses on VA ECMO support as the most familiar treatment strategy in cardiac surgery for treating patients with postoperative cardiac failure.[3] Registry data from the Extracorporeal Life Support Organization have shown a steady increase of extracorporeal life support for postcardiotomy cardiogenic shock over the past decade; however, survival to discharge showed a steady decrease over the past 10 years ranging between 15% and 25%.[21] These disappointing results were similarly described by Fukuhara and colleagues,[22] reviewing the outcome of postcardiotomy cardiogenic shock treated with multiple different extracorporeal support devices between 1993 and 2015, seeing survival rates between 25% and 50%. In contrast, the initial safety trial for Impella 5.0 in postcardiotomy shock showed a favorable outcome, with 30-day and 1-year survival of 94% and 75%[23]; however, strict inclusion criteria excluding cardiopulmonary resuscitation in the 24 hours before implantation as well as active myocardial infarction before implantation among other criteria prohibited a comparison with "real-life" clinical settings for postcardiotomy cardiogenic shock. David and colleagues[24] provided a first insight on the use of the Impella 5.0 device

JTCVS OPEN
@AATSJournals

Early implementation of temporary circulatory support with microaxial pumps in postcardiotomy cardiogenic shock following CABG surgery leads to superior survival

September 2017 - October 2022
All patients undergoing CABG surgery requiring postoperative support with an Impella 5.0/5.5 pump (n = 42).
Subgroups:
Simultaneous Impella implantation: n = 27
Delayed Impella implantation: n = 15





Heart with venous bypass grafts and an thoracica interna graft with implanted Impella 5.5.

Simultaneous implementation of Impella therapy during initial CABG surgery led to a more favorable patient survival, most likely due to the combined advantages of hemodynamic support and LV unloading in patients with ischemic cardiomyopathy.

FIGURE 4. Summary of the analysis on utilizing temporary circulatory support with microaxial pumps in patients with postcardiotomy cardiogenic shock following coronary artery bypass grafting. Early implementation of the temporary assist device leads to a more favorable patient outcome. *CABG*, Coronary artery bypass grafting; *LV*, left ventricular.

in 29 patients with postcardiotomy failure, showing a survival to discharge of 58.6% in this cohort of whom the majority of patients suffered from nonischemic cardiomyopathy.

The beneficial hemodynamic advantage of LV microaxial pumps may be the reduction of LV wall distension while providing sufficient cardiac output, thus leading to cardiac recovery patient survival. Kawashima and colleagues[25] proved the benefit of direct LV venting in a large animal model with acute left-sided myocardial ischemia, comparing the Impella device with VA-ECMO support. The findings revealed a decreased LV end-diastolic pressure as well as a better response to defibrillations for ventricular fibrillations in Impella-supported animals as compared with ECMO-supported animals.

One important detail for a successful outcome following postcardiotomy failure appears to be the timing of Impella implantation. Our data suggest that patients receiving early hemodynamic support within the initial surgery show a more favorable postoperative course as compared with patients undergoing delayed extracorporeal support. These differences in outcome may be due to the avoidance of high-dosage postoperative catecholamine therapy in patients who underwent early Impella implantation, given the known side-effects of vasoconstrictive agents, that may lead to end-organ dysfunction as well as reduced peripheral blood circulation.[26-28] The lower serum bilirubin peak in patients who received simultaneous Impella implantation as compared with patients with delayed LV support in our cohorts underlines the relevance of early extracorporeal device therapy.

Also, these data show a median time on mechanical ventilation of 3.7 days in the simultaneous group and 9.9 days in the delayed group, suggesting a trend towards

longer ventilation in patients in an initially critical hemodynamic state without early hemodynamic support. This is of special importance, since postoperative pneumonia remains a serious complication in patients with heart failure postcardiotomy.[4,29]

Therefore, a center-specific strategy defining clinical parameters (including VIS, intraoperative and postoperative lactate trends, renal function, central venous saturation, and clinical signs of hypoperfusion) when temporary extracorporeal assist device implantation should be performed will be implemented in our center going forward.

One important benefit of the subclavian approach of postoperative Impella support is the advantage of a closed sternum, which allows early weaning off mechanical ventilation as well as the ability to mobilize the patient with ongoing Impella support.

Limitations

The study has the known limitations of a retrospective single-center analysis. Patients were neither randomized nor controlled. In addition, cohort sizes are small, and results do not allow definite conclusions on LV recovery. Yet, the overall good outcome of this cohort demonstrates the potential to successfully bridge patients with postcardiotomy cardiogenic shock after CABG with microaxial pumps.

CONCLUSIONS

In conclusion, our data show a favorable outcome of patients suffering from ischemic cardiomyopathy and concomitant postcardiotomy failure after CABG surgery when receiving early postoperative extracorporeal support with a surgically implantable microaxial pump, despite preoperatively severely reduced LV ejection fraction in both cohorts. Future treatment modalities for postcardiotomy failure may focus further on active LV venting devices, which may lead to reduced LV wall distension, improved myocardial recovery with lower left ventricular end-diastolic pressure, and therefore overall improved postoperative recovery in this challenging patient group (Figure 4).

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Lorusso R, Raffa GM, Alenizy K, Sluijpers N, Makhoul M, Brodie D, et al. Structured review of post-cardiotomy extracorporeal membrane oxygenation: part 1—adult patients. *J Heart Lung Transplant*. 2019;38:1125-43.
2. Stretch R, Sauer CM, Yuh DD, Bonde P. National trends in the utilization of short-term mechanical circulatory support: incidence, outcomes, and cost analysis. *J Am Coll Cardiol*. 2014;64:1407-15.
3. Lorusso R, Whitman G, Milojevic M, Raffa G, McMullan DM, Boeken U, et al. 2020 EACTS/ELSO/STS/AATS expert consensus on post-cardiotomy extracorporeal life support in adult patients. *Eur J Cardiothorac Surg*. 2021;59:12-53.
4. Rastan AJ, Dege A, Mohr M, Doll N, Falk V, Walther T, et al. Early and late outcomes of 517 consecutive adult patients treated with extracorporeal membrane oxygenation for refractory postcardiotomy cardiogenic shock. *J Thorac Cardiovasc Surg*. 2010;139:302-11.e1.
5. Pilarczyk K, Bauer A, Boening A, von der Brelie M, Eichler I, Gohrbandt B, et al German Society for Thoracic and Cardiovascular Surgery, German Society of Cardiology, German Society of Anaesthesiology and Intensive Care Medicine, German Interdisciplinary Association for Intensive Care, German Society for Cardiovascular Engineering. [S3-Guideline: Recommendations for intra-aortic balloon pumping in cardiac surgery]. *Thorac Cardiovasc Surg*. 2015;63(Suppl 2):S131-96 [in German].
6. Beckmann E, Ismail I, Cebotari S, Busse A, Martens A, Shrestha M, et al. Right-sided heart failure and extracorporeal life support in patients undergoing pericardiectomy for constrictive pericarditis: a risk factor analysis for adverse outcome. *Thorac Cardiovasc Surg*. 2017;65:662-70.
7. Navia JL, Atik FA, Beyer EA, Ruda Vega P. Extracorporeal membrane oxygenation with right axillary artery perfusion. *Ann Thorac Surg*. 2005;79:2163-5.
8. Chamogeorgakis T, Lima B, Shafii AE, Nagpal D, Pokersnik JA, Navia JL, et al. Outcomes of axillary artery side graft cannulation for extracorporeal membrane oxygenation. *J Thorac Cardiovasc Surg*. 2013;145:1088-92.
9. Lorusso R, Raffa GM, Heuts S, Lo Coco V, Meani P, Natour E, et al. Pulmonary artery cannulation to enhance extracorporeal membrane oxygenation management in acute cardiac failure. *Interact Cardiovasc Thorac Surg*. 2020;30:215-22.
10. Chen SW, Tsai FC, Lin YS, Chang CH, Chen DY, Chou AH, et al. Long-term outcomes of extracorporeal membrane oxygenation support for postcardiotomy shock. *J Thorac Cardiovasc Surg*. 2017;154:469-77.e2.
11. Bernhardt AM, Potapov E, Schibilsky D, Ruhparwar A, Tschöpe C, Spillmann F, et al. First in man evaluation of a novel circulatory support device: early experience with the Impella 5.5 after CE mark approval in Germany. *J Heart Lung Transplant*. 2021;40:850-5.
12. Zubarevich A, Arjomandi Rad A, Szczechowicz M, Luedike P, Koch A, Pizanis N, et al. Early experience with the Impella pump: single-center registry. *Artificial Organs*. 2022;46:1689-94. https://doi.org/10.1111/aor.14245
13. van Diepen S, Katz JN, Albert NM, Henry TD, Jacobs AK, Kapur NK, et al American Heart Association Council on Clinical Cardiology, Contemporary Management of Cardiogenic Shock: A Scientific Statement From the American Heart Association Council on Cardiovascular and Stroke Nursing, Council on Quality of Care and Outcomes Research, Mission: Lifeline. Contemporary management of cardiogenic shock: a Scientific Statement from the American Heart Association. *Circulation*. 2017;136:e232-68. https://doi.org/10.1161/CIR.0000000000000525
14. Nguyen HV, Havalad V, Aponte-Patel L, Murata AY, Wang DY, Rusanov A, et al. Temporary biventricular pacing decreases the vasoactive-inotropic score after cardiac surgery: a substudy of a randomized clinical trial. *J Thorac Cardiovasc Surg*. 2013;146:296-301.
15. Bernhardt AM, Zipfel S, Reiter B, Hakmi S, Castro L, Söffker G, et al. Impella 5.0 therapy as a bridge-to-decision option for patients on extracorporeal life support with unclear neurological outcomes. *Eur J Cardio Thorac Surg*. 2019;56:1031-6.
16. Eulert-Grehn JJ, Starck C, Kempfert J, Falk V, Potapov E. ECMELLA 2.0: single arterial access technique for a staged approach in cardiogenic shock. *Ann Thorac Surg*. 2021;111:e135-7.
17. Gaies MG, Gurney JG, Yen AH, Napoli ML, Gajarski RJ, Ohye RG, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med*. 2010;11:234-8.
18. Koponen T, Karttunen J, Musialowicz T, Pietiläinen L, Uusaro A, Lahtinen P. Vasoactive-inotropic score and the prediction of morbidity and mortality after cardiac surgery. *Br J Anaesth*. 2019;122:428-36.
19. Pahuja M, Hernandez-Montfort J, Whitehead EH, Kawabori M, Kapur NK. Device profile of the Impella 5.0 and 5.5 system for mechanical circulatory support for patients with cardiogenic shock: overview of its safety and efficacy. *Expert Rev Med Devices*. 2022;19:1-10.
20. Mebazaa A, Pitsis AA, Rudiger A, Toller W, Longrois D, Ricksten SE, et al. Clinical review: practical recommendations on the management of perioperative heart failure in cardiac surgery. *Crit Care*. 2010;14:201.

21. Whitman GJ. Extracorporeal membrane oxygenation for the treatment of postcardiotomy shock. *J Thorac Cardiovasc Surg*. 2017;153:95-101.
22. Fukuhara S, Takeda K, Garan AR, Kurlansky P, Hastie J, Naka Y, et al. Contemporary mechanical circulatory support therapy for postcardiotomy shock. *Gen Thorac Cardiovasc Surg*. 2016;64:183-91.
23. Griffith BP, Anderson MB, Samuels LE, Pae WE Jr, Naka Y, Frazier OH. The RECOVER I: a multicenter prospective study of Impella 5.0/LD for postcardiotomy circulatory support. *J Thorac Cardiovasc Surg*. 2013;145:548-54. https://doi.org/10.1016/j.jtcvs.2012.01.067
24. David CH, Quessard A, Mastroianni C, Hekimian G, Amour J, Leprince P, et al. Mechanical circulatory support with the Impella 5.0 and the Impella left direct pumps for postcardiotomy cardiogenic shock at La Pitié-Salpêtrière Hospital. *Eur J Cardiothorac Surg*. 2020;57:183-8. https://doi.org/10.1093/ejcts/ezz179
25. Kawashima D, Gojo S, Nishimura T, Itoda Y, Kitahori K, Motomura N, et al. Left ventricular mechanical support with Impella provides more ventricular unloading in heart failure than extracorporeal membrane oxygenation. *ASAIO J*. 2011;57:169-76.
26. Hartmann C, Radermacher P, Wepler M, Nußbaum B. Non-hemodynamic effects of catecholamines. *Shock*. 2017;48:390-400.
27. Leyh RG, Kofidis T, Strüber M, Fischer S, Knobloch K, Wachsmann B, et al. Methylene blue: the drug of choice for catecholamine-refractory vasoplegia after cardiopulmonary bypass? *J Thorac Cardiovasc Surg*. 2003;125:1426-31.
28. Weis F, Kilger E, Beiras-Fernandez A, Nassau K, Reuter D, Goetz A, et al. Association between vasopressor dependence and early outcome in patients after cardiac surgery. *Anaesthesia*. 2006;61:938-42.
29. Biffi S, Di Bella S, Scaravilli V, Peri AM, Grasselli G, Alagna L, et al. Infections during extracorporeal membrane oxygenation: epidemiology, risk factors, pathogenesis and prevention. *Int J Antimicrob Agents*. 2017;50:9-16.

Key Words: postcardiotomy cardiogenic shock, Impella 5.5, Impella 5.0, CABG surgery, ischemic cardiomyopathy, LV unloading, temporary mechanical support