7-1-2022

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Cardiovascular Revascularization Medicine 40 (2022) 113–119

Contents lists available at ScienceDirect

Cardiovascular Revascularization Medicine

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ARTICLE INFO

Article history:
Received 27 July 2021
Received in revised form 14 November 2021
Accepted 15 November 2021

Keywords:
Takotsubo syndrome
Acute heart failure
Cardiogenic shock
Impella
ECMO
Mechanical circulatory support

ABSTRACT

Objectives: To analyze the characteristics and outcome of Impella mechanical circulatory support (MCS) for Takotsubo syndrome (TS) with cardiogenic shock.
Background: TS is an acute heart failure syndrome characterized by transient severe reduction of left ventricular (LV) systolic function, with cardiogenic shock occurring in around 10% of patients. Since inotropes should be avoided due to their role in TS pathogenesis and aggravation of LV outflow tract obstruction, the use of MCS as treatment is a viable treatment option, however, studies are lacking.
Methods: The catheter-based ventricular assist device (cVAD) registry and local MCS databases were screened for TS patients with cardiogenic shock (TS-CS) supported with an Impella percutaneous ventricular assist device (pVAD). Patient and treatment characteristics and in-hospital outcomes were retrospectively analyzed.
Results: At 10 US and European centers, 16 TS-CS patients supported with an Impella pVAD were identified between December 2013 and May 2018 (mean age, 61.8 ± 15.5 years; 87.5% women). LV ejection fraction (LVEF) at presentation was severely reduced (mean, 19.4 ± 8.3%). Prior to MCS, 13 patients (81.3%) were mechanically ventilated, 4 patients (25.0%) had been resuscitated, and mean serum lactate was 4.7 ± 3.5 mmol/L. Mean duration of Impella support was 1.9 ± 1.0 days (range, 1–4 days). Thirteen patients (81.3%) survived to discharge, and all survivors experienced cardiac recovery with significant improvement of LVEF at discharge compared to baseline (20.4 ± 8.8 vs. 52.9 ± 12.0, $P < 0.001$).

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https://doi.org/10.1016/j.carrev.2021.11.018

Conclusions: This is the first series of TS-CS patients supported with an Impella pVAD. Mortality was low, and LV systolic function recovered in all survivors. Prospective studies of Impella support in this special condition are warranted.

1. Introduction

Takotsubo syndrome (TS) is an acute heart failure syndrome with risk that is still underestimated [1,2]. In most cases, left ventricular ejection fraction (LVEF) is strongly reduced and left ventricular end-diastolic pressure (LVEDP) is increased [2], reflecting severe cardiac dysfunction [3]. Although myocardial contractility often recovers quickly in TS, patients are at substantial risk during the acute phase for serious adverse events such as cardiogenic shock (CS), arrhythmia, cardiac arrest, and death [2,4].

The true incidence of CS in TS (TS-CS) is not firmly established, which may in part be caused by varying definitions of CS, as well as underdiagnosis of TS in patients with existing CS. An analysis from the National Inpatient Sample database found that CS occurred in 5.2% of TS patients, compared to 8.2% in patients with acute myocardial infarction (AMI) [5]. Interestingly, incidence of CS as well as morbidity significantly increased during the study period (frequency of CS from 2007 to 2014, 4.0% to 19.4%), suggesting that TS was underdiagnosed as the reason of CS in earlier years. In dedicated TS registries, the incidence of CS is frequently reported as 8–12% [2,6–8]. Although in-hospital morbidity and mortality in TS-CS are believed to be lower than in CS complicating AMI (AMICS) [5,6], medical treatment of TS-CS is frequently a therapeutic dilemma. Catecholamines and especially inotropes should be avoided, as they are considered to play an important role during TS pathogenesis [9]. Moreover, TS carries a substantial risk for left ventricular outflow tract obstruction (LVOTO), which may be induced or aggravated by inotropes and predisposes to development of CS [10]. Therefore, the use of mechanical circulatory support (MCS) in TS patients with established shock is increasing.

In general, TS-CS represents an ideal bridge-to-recovery scenario, as myocardial systolic function in TS recovers 'per definition'. However, in most published reports on MCS in TS-CS, extracorporeal membrane oxygenation (ECMO) or intra-aortic balloon pump (IABP) were used [11]. The aim of our study was to analyze patient characteristics and outcomes in a series of patients with TS-CS supported with a percutaneous ventricular assist device (pVAD).

2. Methods

2.1. Study design

Patients supported with an Impella pVAD (Abiomed, Danvers, MA, USA) for TS-CS were retrospectively reviewed at 10 sites (5 centers in the United States, 3 centers in Germany, and 1 each in Denmark, France, and Italy). Patients were identified either by screening of the cVAD registry [12], or through screening local databases by local investigators. Anonymized baseline characteristics, hemodynamic, laboratory, and echocardiographic data, and in-hospital outcomes, were retrospectively provided by each site. The present study is in compliance with the Declaration of Helsinki. Collection and analysis of data were carried out in agreement with data protection laws of each participating site's country and following ethical committee or institutional review board approval at each participating site, if needed.

2.2. Patient population

Patients were included in the analysis if a) TS had been diagnosed in compliance with the InterTAK Diagnostic Criteria [13], and b) they were supported with an Impella device for CS. In brief, patients had to present with transient apical, midventricular, basal, or focal ballooning, as detected by echocardiography or ventriculography, in the absence of coronary arterial lesions accounting for wall motion abnormalities. Patients further should have shown at least temporary ECG changes such as ST-segment elevation, depression, or T-wave inversion, and cardiac biomarker elevation [13]. Of note, it was required to have data on recovery of LV systolic function in survivors, in order to confirm the correct diagnosis of TS [9]. Patients supported with any other MCS device such as IABP, veno-arterial ECMO (V-A ECMO), or Tandem Heart at any time during hospitalization were not considered.

CS was defined as systolic blood pressure (SBP) lower than 90 mmHg or mean arterial blood pressure (MAP) lower than 60 mmHg or a drop higher than 30 mmHg from baseline or the need for inotropes or vasopressors to maintain blood pressure above the aforementioned targets, according to the Society for Cardiovascular Angiography & Intervention (SCAI) clinical expert consensus statement on the classification of cardiogenic shock [14]. Right ventricular involvement was per site reporting, with no standardized definition. For analyzing LV systolic dysfunction and recovery, the lowest available LVEF between admission and initiation of Impella support, and the highest available in-hospital LVEF after Impella removal, were compared. LVEF could be calculated from ventriculography or echocardiography. Complications were defined as clinical appearance of stroke or transitory ischemic attack (TIA), minor access site bleeding, major bleeding at any location requiring blood transfusion, vascular complication at the Impella insertion site requiring surgical repair, acute kidney injury as 1.5-fold increase in serum creatinine, need for dialysis, and hemolysis as plasma free hemoglobin > 40 mg/dL on two occasions within 72 h after Impella initiation.

2.3. Statistics

Statistical analyses were performed by A.M. with JMP version 10 software (SAS Institute Inc., Cary, NC). Data are presented as mean $\pm$ SD or median with interquartile range (IQR). Categorical variables are presented as N (%) and compared using the Fisher's exact test. Normally distributed variables were compared using the Student's *t*-test and skewed continuous variables using the Wilcoxon rank-sum test. A two-sided P-value less than 0.05 was considered statistically significant.

3. Results

3.1. Baseline characteristics

A total of 16 TS-CS patients supported with an Impella device (Fig. 1A) from December 2013 to May 2018 were identified across 10 European and US centers. Mean age was 61.8 $\pm$ 15.5 years and 14 patients (87.5%) were female. Apical TS was observed in 14 patients (87.5%). Five patients (31.3%) had a physical trigger and six patients (37.5%) had an emotional trigger. There were no patients who had both an emotional and physical trigger for TS. Two patients (16.7%) had right ventricular involvement. Four patients had coexisting coronary artery disease, without significant lesions. There were no patients who received PCI. Complete baseline data are presented in Tables 1 and 2.

3.2. Hemodynamics and treatment characteristics

Prior to MCS, all patients had clinical and laboratory signs of CS. Thirteen patients presented with shock already on admission. While one

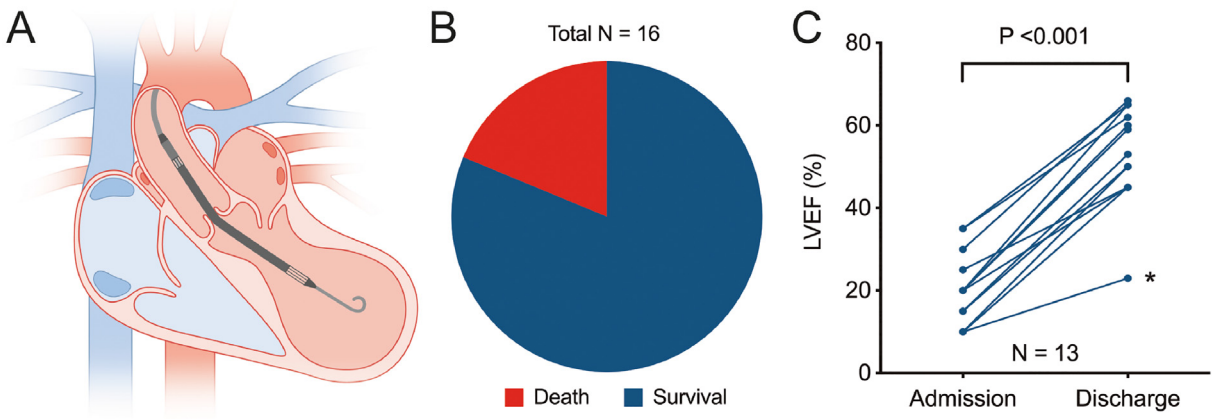

Fig. 1. Impella mechanical circulatory support in Takotsubo syndrome. A: Schematic of an Impella CP in a heart with apical Takotsubo syndrome. Note that the left ventricular outflow tract is physically bridged. B: In-hospital survival. C: Left ventricular ejection fraction (LVEF) before and after Impella support in surviving patients. One patient (asterisk) had an increase in LVEF from 10% to only 23%, but LVEF fully recovered during subsequent rehabilitation.

patient had SCAI shock stage B, the remaining 15 patients had stage C or D shock prior to Impella implantation. Beyond TS, there were no other reasons for shock such as bleeding or sepsis. Hemodynamic and treatment characteristics are presented in Tables 2, 3 and 4. Pre-Impella mean pH was 7.24 ± 0.21 and mean lactate was 4.7 ± 3.5 mmol/L. Mean systolic blood pressure was 90.1 ± 20.2 mm Hg in the presence of 2.1 ± 0.9 catecholamines; mean LVEF was 19.4% ± 8.3%. Prior to Impella support, 14 out of 16 patients had at least one inotrope. Thirteen patients (81.3%) were mechanically ventilated, and four patients (25.0%) had experienced cardiac arrest with cardiopulmonary resuscitation (CPR). Thirteen of 16 patients had CS on admission, therefore time from onset of shock to Impella insertion could not be assessed. An Impella device was implanted on the day of admission in 10 patients (all of whom had shock present on admission), and 3 patients received Impella support one day after admission. Seven patients (43.8%) were implanted with an Impella 2.5 and 9 patients (56.3%) with an Impella CP. The median support time was 1.9 ± 1.0 days (range, 1–4 days). Twelve patients (80.0%) had anticoagulation with heparin, and 1 patient

Table 1
Baseline characteristics.

Characteristic	All N = 16	Survivors N = 13	Non-survivors N = 3	P value
Age, years	61.8 ± 15.5 (16)	62.4 ± 16.6 (13)	59.3 ± 11.6 (3)	0.73
Female sex	87.5% (14/16)	84.6% (11/13)	100% (3/3)	0.99
BMI, kg/m^2	27.6 ± 5.5 (16)	27.7 ± 6.1 (13)	27.2 ± 2.8 (3)	0.84
Cardiovascular risk factors				
Smoking	18.8% (3/16)	15.4% (2/13)	33.3% (1/3)	0.49
Hypertension	62.5% (10/16)	69.2% (9/13)	33.3% (1/3)	0.52
Diabetes	18.8% (3/16)	15.4% (2/13)	33.3% (1/3)	0.49
Hypercholesterolemia	37.5% (6/16)	38.5% (5/13)	33.3% (1/3)	0.99
Family history for cardiovascular events	7.7 (1/13)	9.1% (1/11)	0% (0/2)	0.99
Medical history				
COPD	6.3% (1/16)	0.0% (0/13)	33.3% (1/3)	0.19
Asthma	6.3% (1/16)	7.7% (1/13)	0/0% (0/3)	0.99
Prior TIA/stroke	0.0% (0/16)	0.0% (0/13)	0.0% (0/3)	0.99
Prior myocardial infarction	25.0% (4/16)	30.8% (4/13)	0% (0/3)	0.53
Prior PCI	12.5% (2/16)	15.4% (2/13)	0.0% (0/3)	0.99
Prior CABG	0.0% (0/16)	0.0% (0/13)	0.0% (0/3)	0.99
Symptoms on admission				
Cardiogenic shock on admission	81.3% (13/16)	76.9% (10/13)	100.0% (3/3)	0.99
Chest pain	56.3% (9/16)	53.9% (7/13)	66.7% (2/3)	0.99
Dyspnea	62.5% (10/16)	69.2% (9/13)	33.3% (1/3)	0.52
Syncope	25.0% (4/16)	30.8% (4/13)	0.0% (0/3)	0.53
ECG on admission				
Sinus rhythm	85.7% (12/14)	100.0% (11/11)	33.3% (1/3)	0.03
Atrial fibrillation	14.3% (2/14)	0.0% (0/11)	66.7% (2/3)	0.03
ST-segment elevation	57.1% (8/14)	58.3% (7/12)	50.0% (1/2)	0.99
ST-segment depression	16.7% (2/12)	20.0% (2/10)	0.0% (0/2)	0.99
LBBB	23.1% (3/13)	20.0% (2/10)	33.3% (1/3)	0.99
T wave inversion	36.4% (4/11)	33.3% (3/10)	100% (1/1)	0.36
Apical Takotsubo type	87.5% (14/16)	84.6% (11/13)	100% (3/3)	0.99
Right ventricular involvement	16.7% (2/12)	11.1% (1/9)	33.3% (1/3)	0.45
Trigger				
Physical	31.3% (5/16)	30.8% (4/13)	33.3% (1/3)	0.99
Emotional	37.5% (6/16)	38.5% (5/13)	33.3% (1/3)	0.99

BMI, body mass index; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; LBBB, left bundle branch block; PCI, percutaneous coronary intervention; SD, standard deviation.

Table 2
Patient-level characteristics and clinical outcome through hospital discharge.

Patient	Sex	Age	TS type	Physical trigger	Emotional trigger	Chest pain on admission	ST-elevation on admission	Afib on admission	Cardiogenic shock on admission	CPR prior to Impella
1	Female	47	Apical	No	Yes	Yes	n/a	Yes	Yes	No
2	Female	56	Basal	No	Yes	Yes	Yes	No	Yes	No
3	Female	29	Apical	Yes	No	No	No	No	Yes	Yes
4	Female	70	Apical	Yes	No	No	No	Yes	Yes	Yes
5	Female	77	Apical	No	No	No	No	No	Yes	No
6	Female	79	Apical	No	No	No	Yes	No	Yes	No
7	Female	76	Apical	No	Yes	Yes	Yes	No	Yes	No
8	Female	76	Apical	Yes	No	No	No	No	No	No
9	Male	55	Apical	No	Yes	Yes	Yes	n/a	Yes	No
10	Female	71	Apical	No	No	Yes	Yes	No	Yes	No
11	Female	81	Apical	No	Yes	Yes	Yes	No	Yes	No
12	Female	43	Apical	No	No	Yes	n/a	n/a	No	Yes
13	Male	55	Basal	Yes	No	No	Yes	No	Yes	No
14	Female	61	Apical	No	No	Yes	Yes	No	Yes	Yes
15	Female	44	Apical	No	Yes	Yes	No	No	Yes	No
16	Female	69	Apical	Yes	No	No	No	No	No	No

AFib, atrial fibrillation; CPR, cardiopulmonary resuscitation; n/a, data not available; TS, Takotsubo syndrome.

(6.7%) had bivalirudin. Two patients (13.3%) were managed without systemic anticoagulation. Of those, one had 2 and one had 3 days of Impella pVAD support.

3.3. In-hospital outcomes

Of 16 patients, 13 patients (81.3%) survived to discharge, and 3 patients (18.8%) died (Fig. 1B). There were no statistically significant differences in baseline characteristics between survivors and non-survivors, except for atrial fibrillation on ECG at admission. Atrial fibrillation was absent in survivors but present in 66.7% of non-survivors ($P = 0.03$). Before Impella support, non-survivors had significantly higher heart rates (mean 129.0 ± 10.1 vs. 106.0 ± 26.9 beats per minute, $P = 0.04$) and significantly lower systolic blood pressures (mean 73.0 ± 7.2 vs. 94.0 ± 20.3 mm Hg, $P = 0.02$). Two of 3 non-survivors (66.7%) had CPR before Impella support, whereas only 2 out of 13 survivors (15.4%) had been resuscitated ($P = 0.21$). Survivors had longer duration of support (mean 2.0 ± 1.0 days vs. 1.3 ± 0.6 days, $P = 0.18$). Dislocation of an Impella CP occurred in 1 patient after 3 days, and the device was removed. Clinical stroke or TIA did not occur in any patient. Minor bleeding was noticed in 4 and major bleeding in 1 patient, respectively. Hemolysis was observed in 3 patients, without clinical sequelae.

All survivors experienced myocardial recovery, with a strong improvement of LV systolic function at discharge compared to baseline (LVEF 20.4% ± 8.8% on admission vs. 52.9% ± 12.0% before discharge, $P < 0.001$, Fig. 1C). One patient had a moderate LVEF change from 10% to 23% during hospitalization, but LV systolic function fully recovered during subsequent rehabilitation. All surviving patients had a favorable neurological outcome, without impairment or clinical signs of cerebral embolism. From the 2 reported patients who had right ventricular involvement as assessed by echocardiography, one survived with full recovery (5-day length of hospital stay), whereas the other patient died on the day of admission, but the cause of deterioration and death could not be ascertained due to the retrospective nature of this analysis.

4. Discussion

Here we report the first series of TS patients with cardiogenic shock supported with a percutaneous Impella pVAD. Most patients had apical TS and were otherwise representative of larger TS cohorts, comprised primarily of women with typical prevalence of physical or emotional triggers. Despite profound shock in this cohort, hospital survival was 81.3% and LV systolic function recovered in all surviving patients.

The patients in this cohort represent the most severely compromised patients on the TS spectrum. Indeed, the majority of patients were already in CS on admission, and prior to Impella pVAD support LVEF was severely reduced and LVEDP strongly increased. Nearly all patients were severely hypotensive in the presence of catecholamines and required mechanical ventilation, with one-fourth having undergone CPR for cardiac arrest, all portending poor prognosis. Nevertheless, 13 of 16 patients survived to discharge and showed full recovery of cardiac systolic function. Due to the retrospective nature of this study, it was not possible to influence timing of support and other measures of clinical management. Time on support was rather short (mean 1.9 days, range 1–4 days) compared to MCS strategies in AMICS, which may be explained by the frequently rapid improvement of systolic function that is a hallmark of TS.

Published data on MCS in TS-CS are limited. While IABP or veno-arterial ECMO have been used in the majority of cases so far [11], Impella support has only been reported in single cases to date. Importantly, V-A ECMO increases afterload and potentially worsens mitral regurgitation, and IABP may induce or aggravate LVOTO in TS [15]. In contrast, pVADs actively unload the LV and physically bridge the potentially obstructed LVOT (Fig. 1A), and therefore appear favorable for TS [16].

We propose that active unloading in patients with established TS-CS would overall result in improved outcomes. Eventually, early Impella pVAD use in patients with TS-CS may allow for fully avoiding the use of catecholamines and especially inotropes in CS. This novel concept has been demonstrated in the literature in a single patient with TS-CS and LVOTO, who received MCS with an Impella CP [17]. This patient did not require catecholamines, and Impella support allowed for administration of short-acting intravenous betablockers to treat LVOTO. Finally, LV systolic function fully recovered and the patient was discharged. With this experience, we propose that a TS-specific shock protocol is required [9], given the unique features of this condition, which are in many respects different from AMI or decompensated chronic heart failure. As shock was obviously more severe in non-surviving patients in our cohort, we speculate that earlier initiation of MCS with Impella could have contributed to a better prognosis. Alternatively, very profound shock may require ECMO support in the beginning, which could involve Impella use for LV venting, which later allows for ECMO weaning.

Taken together, our data demonstrate the feasibility of Impella pVAD support in TS with CS. In general, the risk of complications from MCS should be carefully weighed against the potential benefit, but also against the risk of further shock progression and deterioration. In our

Lactate pre Impella (mmol/L)	Heart rate pre Impella (beats per minute)	Systolic blood pressure pre Impella (mmHg)	Number of catecholamines pre Impella	Invasive ventilation	Impella type	Duration of support (days)	Survival to discharge	Post Impella highest LVEF (%)
5.9	140	75	3	Yes	CP	2	No	–
6.0	135	100	2	Yes	CP	3	Yes	50
4.4	72	100	2	Yes	2.5	3	Yes	66
1.6	127	65	2	Yes	CP	1	No	–
13.8	105	150	2	Yes	CP	2	Yes	65
2.6	127	100	2	No	CP	1	Yes	23
0.8	67	79	3	Yes	CP	1	Yes	59
1.0	121	98	2	Yes	CP	3	Yes	53
n/a	78	80	3	Yes	CP	1	Yes	62
7.0	100	80	2	No	2.5	4	Yes	45
3.7	130	80	2	Yes	CP	1	Yes	45
n/a	116	75	1	Yes	2.5	2	Yes	50
n/a	125	75	0	Yes	2.5	1	Yes	65
n/a	120	79	2	Yes	2.5	1	No	–
4.7	65	106	1	No	2.5	2	Yes	60
5.1	137	99	4	Yes	2.5	2	Yes	45

cohort, major complications were rather rare, although definitive evidence can only be derived from larger studies. Mortality of TS-CS is lower compared to AMICS, but the required time on MCS support is likely shorter, which should limit the rate of MCS-related complications. Recently, some studies have questioned the safety and efficacy of MCS with Impella in CS [18,19], while others have suggested a favorable safety and efficacy profile [20]. This heterogenous evidence likely contributes to differing frequencies of Impella use across centers. Well-designed, prospective randomized trials such as RECOVER IV and DanGer are ongoing to assess safety, efficacy, and timing of Impella use in AMICS.

Overall, given the difficult medical management of TS-CS and the relatively low rate of complications, selected patients, especially those with LVOTO and profound shock, may be candidates for Impella support. Our data set the stage for a future prospective trial, in order to assess the potential benefit of MCS with Impella in this special patient population.

5. Conclusion

This is the first series of TS-CS patients supported with an Impella pVAD. Despite refractory CS and severely depressed LVEF, outcomes

Table 3
Hemodynamics and treatment characteristics.

Characteristic	All N = 16	Survivors N = 13	Non-survivors N = 3	P value
Status before Impella				
Heart rate, bpm	110.3 ± 26.1 (16)	106.0 ± 26.9 (13)	129.0 ± 10.1 (3)	0.04
Systolic blood pressure, mm Hg	90.1 ± 20.2 (16)	94.0 ± 20.3 (13)	73.0 ± 7.2 (3)	0.01
Diastolic blood pressure, mm Hg	55.4 ± 16.6 (16)	56.9 ± 17.8 (13)	48.7 ± 8.1 (3)	0.26
LVEF pre-Impella, %	19.4 ± 8.3 (16)	20.4 ± 8.8 (13)	15.0 ± 5.0 (3)	0.21
LVEDP, mm Hg	30.3 ± 6.5 (9)	29.4 ± 6.2 (8)	38.0 (1)	n.a.
Cardiac arrest prior to Impella[a]	25.0% (4/16)	15.4% (2/13)	66.7% (2/3)	0.14
pH	7.24 ± 0.21 (12)	7.20 ± 0.23 (9)	7.34 ± 0.13 (3)	0.21
Lactate, mmol/L	4.7 ± 3.5 (12)	4.9 ± 3.7 (10)	3.8 ± 3.0 (2)	0.69
Catecholamines	93.8% (15/16)	92.3% (12/13)	100.0% (3/3)	0.99
Number of catecholamines pre Impella	2.1 ± 0.9 (16)	2.0 ± 1.0 (13)	2.3 ± 0.6 (3)	0.47
Dobutamine	37.5% (6/16)	38.5% (5/13)	33.3% (1/3)	0.99
Epinephrine	50.0% (8/16)	46.2% (6/13)	66.7% (2/3)	0.99
Norepinephrine	87.5% (14/16)	84.6% (11/13)	100.0% (3/3)	0.99
Vasopressin	6.25% (1/16)	7.7% (1/13)	0.0% (0/3)	0.99
Milrinone	25.0% (4/16)	23.1% (3/13)	33.3% (1/3)	0.99
Mechanical ventilation	81.3% (13/16)	76.9% (10/13)	100.0% (3/3)	0.99
Impella support				
Impella 2.5	43.8% (7/16)	46.2% (6/13)	33.3% (1/3)	0.99
Impella CP	56.3% (9/16)	53.9% (7/13)	66.7% (2/3)	0.99
Anticoagulation				0.48
Heparin	80.0% (12/15)	83.3% (10/12)	66.7% (2/3)	
Bivalirudin	6.7% (1/15)	8.3% (1/12)	0.0% (0/3)	
None	13.3% (2/15)	8.3% (1/12)	33.3% (1/3)	
Duration of support, days	1.9 ± 0.95 (16)	2.0 ± 1.0 (13)	1.3 ± 0.58 (3)	0.18
Impella removed on site	68.8% (11/16)	84.6% (11/13)	0.0% (0/3)	0.04
Impella removed with vascular surgery	12.5% (2/13)	15.4% (2/13)	0.0% (0/3)	0.5
Death on support	25.0% (3/16)	0.0% (0/13)	100.0% (3/3)	0.002
LVEF at discharge, %	52.9 ± 12.0 (13)	52.9 ± 12.0 (13)		n.a.

CPR, cardiopulmonary resuscitation; LVEDP, left ventricular end-diastolic pressure; LVEF, left ventricular ejection fraction; MCS, mechanical circulatory support; n.a., not applicable; SD, standard deviation.

[a] Either out-of-hospital or in-hospital cardiac arrest.

Table 4
Complications during hospitalization.

Complication	All N = 16	Survivors N = 13	Non-survivors N = 3	P value
Stroke/TIA	0% (0/16)	0% (0/13)	0% (0/3)	n/a
Minor access site bleeding	25.0% (4/16)	30.8% (4/13)	0.0% (0/3)	0.53
Major bleeding requiring blood transfusion	6.3% (1/16)	7.7% (1/13)	0.0% (0/3)	0.99
Vascular complication at access site requiring surgical repair	6.3% (1/16)	7.7% (1/13)	0.0% (0/3)	0.99
Acute kidney injury	37.5% (6/16)	30.8% (4/13)	66.7% (2/3)	0.52
Need for dialysis	12.5% (2/16)	7.7% (1/13)	33.3% (1/3)	0.35
Hemolysis	23.1% (3/13)	20.0% (2/10)	33.3% (1/3)	0.49

n/a, not applicable; TIA, transitoric ischemic attack.

were favorable with good survival and full recovery of LV systolic function in surviving patients. These data support prospective studies on MCS with Impella devices in TS-CS.

5.1. Limitations

This study is limited by its retrospective design and by the small number of patients available for analysis, despite the contribution of several European and US centers. Therefore, selection bias may apply, and the results of this study should be regarded as hypothesis-generating. We are further limited by incomplete datasets for some patients, weakening our ability to present a more detailed clinical profile. In particular, pulmonary artery catheter measurements were not available for most patients in this retrospective series.

CRediT authorship contribution statement

L. Christian Napp: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Supervision, Data curation, Writing – original draft, Writing – review & editing. **Ralf Westenfeld:** Investigation, Data curation, Writing – review & editing. **Jacob E. Møller:** Investigation, Data curation, Writing – review & editing. **Federico Pappalardo:** Investigation, Data curation, Writing – review & editing. **Karim Ibrahim:** Investigation, Data curation, Writing – review & editing. **Laurent Bonello:** Investigation, Data curation, Writing – review & editing. **Charles Wilkins:** Investigation, Data curation, Writing – review & editing. **Ashish Pershad:** Investigation, Data curation, Writing – review & editing. **Salvatore F. Mannino:** Investigation, Data curation, Writing – review & editing. **Theodore L. Schreiber:** Investigation, Data curation, Writing – review & editing. **Patrick A. Hall:** Investigation, Data curation, Writing – review & editing. **Amin M. Medjamia:** Investigation, Formal analysis, Data curation, Writing – review & editing. **Jean M. Haurand:** Investigation, Data curation, Writing – review & editing. **Jan-Thorben Sieweke:** Investigation, Data curation, Writing – review & editing. **Andreas Schäfer:** Investigation, Data curation, Writing – review & editing. **Cindy L. Grines:** Investigation, Data curation, Writing – review & editing. **Daniel Burkhoff:** Writing – review & editing. **Jeffrey W. Moses:** Investigation, Data curation, Writing – review & editing. **E. Magnus Ohman:** Investigation, Data curation, Writing – review & editing. **William W. O'Neill:** Investigation, Data curation, Writing – review & editing. **Navin K. Kapur:** Investigation, Data curation, Writing – review & editing. **Johann Bauersachs:** Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: LCN: consultant, lecture and proctoring honoraria, and restricted research funding from Abiomed, lecture honoraria from Abbott and Maquet. Other relationships beyond the topic of this work exist. RW: lecture fees and a restricted research grant from Abiomed. LB: Lecture fees from Abiomed and Boston Scientific, and research grants from AstraZeneca, Biotronik and Abbott. CG: Abiomed advisory board. AMM: is an employee of Abiomed Inc. AS: lecture fees and a restricted research grant from Abiomed. DB: Unrestricted institutional educational grant to Cardiovascular Research Foundation from Abiomed. EMO: Research grants from Abiomed and Chiesi, and consultant to Cytokinetics, Pfizer, and AstraZeneca. JB: lecture fees and a restricted research grant from Abiomed. All other authors reported no conflicts of interest related to this work. The authors are solely responsible for the design and conduct of this study, all study analyses, the drafting and editing of the paper, and its final contents.

Acknowledgements

This study was supported by the German Research Foundation (Clinical Research Unit KFO311). The authors thank Dana Bentley for proofreading the manuscript.

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