The Impella 2.5 and 5.0 devices for ST-elevation myocardial infarction patients presenting with severe and profound cardiogenic shock: The Academic Medical Center intensive care unit experience*

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Objective: **Cardiogenic shock remains an important therapeutic challenge, with high in-hospital mortality rates. Mechanical circulatory support may be beneficial in these patients. Since the efficacy of the intra-aortic balloon pump seems limited, new percutaneously placed mechanical left ventricular support devices, such as the Impella system, have been developed for this purpose. Our current purpose was to describe our experience with the Impella system in patients with ST-elevation myocardial infarction presenting in profound cardiogenic shock, who were admitted to our intensive care unit for mechanical ventilation.**

Methods: **From January 2004 through August 2010, a total of 34 ST-elevation myocardial infarction patients with profound cardiogenic shock were admitted to our intensive care unit and treated with either the Impella 2.5 or the Impella 5.0 device. Baseline and follow-up characteristics were collected retrospectively.**

Measurements and Main Results: **Within the study cohort, 25 patients initially received treatment with the Impella 2.5, whereas nine patients received immediate Impella 5.0 support. Eight out of 25 patients in the Impella 2.5 group were upgraded to 5.0 support. After 48 hrs, 14 of 25 patients in the 2.5 group were alive, five of whom had been upgraded. In the 5.0 group, eight out of nine patients were alive. After 30 days, six of 25 patients in the 2.5 group were alive, three of whom had been upgraded. In the 5.0 group, three of nine patients were alive at 30 days.**

Conclusions: **In ST-elevation myocardial infarction patients with severe and profound cardiogenic shock, our initial experience suggests improved survival in patients who received immediate Impella 5.0 treatment, as well as in patients who were upgraded from 2.5 to 5.0 support, when compared to patients who received only Impella 2.5 support. (Crit Care Med 2011; 39: 2072–2079)**

KEY WORDS: cardiogenic shock; intensive care medicine; mechanical circulatory support

Cardiogenic shock (CS) remains an important therapeutic challenge. Despite advances in treatment, including immediate revascularization for ST-elevation myocardial infarction (STEMI) (1), current in-hospital mortality rates are still around 40% to 50% (2). Traditionally, mechanical circulatory support has been proposed to be beneficial in these patients. The intra-aortic balloon pump (IABP), developed in the 1960s (3), has a Class I guideline recommendation for CS as a complication of STEMI and is therefore widely used for mechanical cardiac support (4). However, no survival benefit could be demonstrated in a recently performed meta-analysis of IABP usage in STEMI (5). Other mechanical circulatory support systems have been developed, including the Impella system (Abiomed Europe GmbH). Two versions of this pump system have been developed, the first of which is the Impella 2.5 pump, which delivers a maximum flow of 2.5 L per minute and is inserted percutaneously. The other, larger pump is the Impella 5.0, which provides a maximum support level of 5 L per minute but requires surgical cutdown of the femoral or axillary artery (6). We introduced the Impella system in our institution in 2004 (7). Besides the application of Impella treatment in the setting of high-risk percutaneous coronary intervention and STEMI without CS (8–12), we used both Impella devices in STEMI patients presenting with CS. The purpose of the current report is to describe our experience with both devices in STEMI patients with severe and profound CS requiring admission to our intensive care unit (ICU) for mechanical ventilation.

METHODS

Patient Population and Data Collection

Since 2004, all patients treated with either Impella device have been entered into a dedicated database. For the current study, all patients who were admitted to our ICU with CS

*See also p. 2186.

From the Departments of Cardiology (AEE, KDS, MMV, JB, JGT, RJdW, JJP, JPJMH), Cardiothoracic Surgery (RC, AHD, BASdM), and Intensive Care Medicine (MdJ, WKL, JAPvdS), AMC Heart Center, Academic Medical Center, Amsterdam, The Netherlands.

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as a complication of STEMI from January 2004 through August 2010 and who received treatment with either the Impella 2.5 device or the Impella 5.0 device were included. Thirty-four patients were identified from our records. Data on previous medical history, the presence of risk factors, hemodynamic status, laboratory measurements, inotropic therapy, and duration of pump support were obtained through a validated ICU patient data management system (MetaVision, iMDsoft, MA). In addition, for in-hospital deaths, information on date of death and death etiology were obtained through chart review. For outpatients, vital status was verified through the records of the Dutch national population registry (Statistics Netherlands, Voorburg, The Netherlands). In case of missing data, outpatient reports were reviewed and general practitioners or treating cardiologists were contacted by telephone. The study was approved by the Academic Medical Center's Institutional Review Board, which, because of the retrospective nature of the study, waived the need for informed consent.

Definitions

CS was largely a clinical diagnosis based on the definition from the SHOCK trial (1), which was a systolic blood pressure equal to or below 90 mm Hg for at least 30 mins or vasopressors required to maintain blood pressure >90 mm Hg, evidence of end-organ hypoperfusion (e.g., urine output <30 mL or cold, diaphoretic extremities or altered mental status), and evidence of elevated filling pressures (e.g., pulmonary congestion on examination or chest radiograph). Profound CS was defined as CS accompanied by the need for high-dose inotropes and vasopressors and admission to the ICU for mechanical ventilation.

Treatment

The decision for implantation of either Impella device was made after primary percutaneous coronary intervention upon the diagnosis of profound CS, unresponsive to intravenous inotropes, and IABP support. All patients were treated with unfractionated heparin, aspirin, and clopidogrel. The administration of GpIIb/IIIa inhibitors was at the discretion of the treating physician. Impella implantation was performed as soon as possible after the diagnosis of profound CS. Device choice was at the discretion of the treating physician. As Impella 2.5 implantation is faster and does not require surgical cutdown of the femoral artery, STEMI patients in profound CS were initially treated with a 2.5 pump in the majority of cases. However, upon increasing experience and intensified collaboration of cardiology and cardiac surgery departments, facilities for inserting the 5.0 pump at the catheterization laboratory increased. Subsequently, the number of STEMI patients in profound CS who received a 5.0 pump as initial treatment increased over time.

Impella System

The Impella 2.5 device (Abiomed Europe GmbH, Aachen, Germany) has been described previously (8). It is a 9F catheter-mounted microaxial rotary blood pump (12F), designed for short-term mechanical circulatory support, which is inserted through the femoral artery and positioned across the aortic valve into the left ventricle using fluoroscopy. The driving console of the pump allows management of pump speed (by 9 gradations) and displays the pressure difference between inflow and outflow, which gives an indication for pump position. The device provides a flow of up to 2.5 L/min at its maximal rotation speed of 51,000 rpm through expelling blood from the left ventricle into the ascending aorta.

The Impella 5.0 device (Abiomed Europe GmbH, Aachen, Germany) is mounted on a 9F catheter as well; however, the pump itself is 21F in diameter. The device is inserted through a Dacron graft sewn onto the femoral artery. The subsequent positioning is similar to the Impella 2.5 placement; however, the 5.0 device is capable of generating a maximum flow of 5.0 L/min.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS, Chicago, IL; version 16.0.2). Continuous data are presented as mean ± SD (median and interquartile range for skewed variables). Categorical data are presented as percentages. The study population was divided into two groups based on the initial treatment, which was either the Impella 2.5 or the Impella 5.0. Importantly, patients who initially received treatment with the Impella 2.5 device and who were upgraded to a 5.0 device during their clinical course, were included in the "2.5-group." Baseline characteristics and clinical course of both groups were compared according to intention-to-treat analysis, which is defined as the initial treatment. Differences between patients treated with the Impella 2.5 and 5.0 were tested using the chi-square test for categorical variables (or Fisher's exact test as appropriate) and the unpaired Student's t test for normally distributed continuous variables (or Mann-Whitney U test as appropriate). All p values $<.05$ were considered statistically significant.

RESULTS

Patients

From 2006 through August 2010, 34 patients were admitted to our ICU for CS as a complication of STEMI and treated with an Impella 2.5 and/or Impella 5.0 device. Baseline characteristics are displayed in Table 1. Twenty-five patients were initially treated with the Impella 2.5 device (2.5 group), whereas in nine out of 34 patients, Impella 5.0 support was the initial treatment modality (5.0 group). In the majority of cases, mechanical ventilation and inotropic medication had been initiated before Impella implantation. More than half of the patients had been resuscitated for out-of-hospital cardiac arrest. The culprit lesion was located in the left main or left anterior descending coronary artery in the majority of patients. Laboratory measurements showed acidosis (pH <7.35) and elevated plasma lactate levels (i.e., >2 mmol/L). No significant differences could be demonstrated between groups.

Clinical Course of Impella 2.5 vs. Impella 5.0

The clinical course of Impella 2.5- vs. Impella 5.0-treated patients is summarized in Table 2 and Figure 1. Median total support time for patients in the 2.5 group was 50 hrs (interquartile range 6–231 hrs); for the 5.0-treated patients, median support time was 129 hrs (interquartile range 82–293 hrs), p = not significant. No differences were demonstrated between groups with regard to mean arterial blood pressure, the need for inotropic therapy, dialysis, or mechanical ventilation at 6 and 48 hrs after admission. Importantly, eight of 25 patients (32%) in the 2.5 group were upgraded to a 5.0 device during treatment. Five out of eight upgraded patients were upgraded within 48 hrs after admission. As displayed in Figure 1, 20 of 25 patients in the 2.5 group were alive after 6 hrs, compared to nine of nine patients in the 5.0 group. After 48 hrs, 14 of 25 patients were alive in the 2.5 group, five of whom had been upgraded to a 5.0 device. In the 5.0 group, eight of nine patients were alive at 48 hrs. After 30 days, six of 25 patients were alive in the 2.5 group, three of whom had been upgraded to a 5.0 device. In the 5.0 group, three of nine patients were alive at 30 days.

Table 1. Baseline characteristics of patients who were initially treated with Impella 2.5 versus patients who received immediate Impella 5.0 support

Patient Characteristics	Impella 2.5 (n = 25)	Impella 5.0 (n = 9)	p
Age (mean ± SD)	58 ± 10	61 ± 11	.64
Male (%)	23 (92)	6 (67)	.07
Hypertension (%)	9 (36)	1 (11)	.16
Smoking (%)	7 (28)	2 (22)	.74
Diabetes mellitus (%)	3 (12)	0 (0)	.28
Family history of coronary artery disease (%)	4 (16)	2 (22)	.68
Previous myocardial infarctions (%)	7 (28)	1 (11)	.31
Hyperlipidemia (%)	1 (4)	0 (0)	.54
Multivessel disease (%)	21 (84)	6 (67)	.27
Resuscitated before presentation (%)	14 (56)	6 (67)	.58
ST-elevation myocardial infarction characteristics			
Ischemic time[a] (median, interquartile range)	188 (114–271)	135 (90–198)	.29
Infarct-related artery			.31
Left main coronary artery (%)	10 (40)	3 (33)	
Left anterior descending coronary artery (%)	14 (56)	4 (44)	
Right coronary artery (%)	1 (4)	1 (11)	
Left circumflex coronary artery (%)	0 (0)	1 (11)	
Thrombolysis in myocardial infarction			
0 flow before percutaneous coronary intervention (%)	25 (100)	9 (100)	1.0
3 flow after percutaneous coronary intervention (%)[b]	17 (74)	3 (43)	.10
Stent placement (%)	18 (72)	7 (78)	
Stent length (mm) mean ± SD	31 ± 17	30 ± 13	.92
Bare-metal stent (%)	25 (83)	7 (100)	.25
Laboratory and hemodynamic measurements at admission			
pH mean ± SD[c]	7.11 ± 0.25	7.15 ± 0.11	.67
Lactate mean ± SD[d]	5.7 ± 3.4	6.1 ± 2.3	.81
Glucose mean ± SD[a]	15.7 ± 5.8	15.6 ± 7.0	.95
Mean arterial blood pressure (mm Hg)[b]	68 ± 22	58 ± 9	.22
Other adjunctive treatment			
Abciximab (%)	11 (44)	2 (22)	.25
Intra-aortic balloon pump (%)	10 (40)	5 (56)	.42
Inotropic therapy before Impella implantation (%)	23 (92)	8 (89)	.78
Mechanical ventilation before Impella implantation (%)	23 (92)	9 (100)	.38

[a]Data available in 21 and 6 patients, respectively; [b]data available in 20 and 8 patients, respectively; [c]data available in 22 and 9 patients, respectively; [d]data available in 13 and 9 patients, respectively.

Impella 2.5-Treated Patients (n = 17)

The clinical course of 30-day survivors as well as deceased patients who were not upgraded to the Impella 5.0 is detailed in Table 3. In brief, the clinical condition of the majority of the deceased patients (eight of 14) deteriorated rapidly within the first 24 hrs after admission, despite Impella 2.5 support and high-dose inotropic therapy. Two patients were stabilized initially; however, sudden deterioration between 24 and 48 hrs after admission and rapid deterioration occurred, despite Impella 2.5 support and high-dose inotropes. In the other four patients, three died of other causes, such as sepsis, after the device had been removed. One patient did not show signs of recovery, and although there was no acute hemodynamic instability, his clinical condition deteriorated slowly and the patient eventually died. In one of the 30-day survivors, limb ischemia occurred for which surgery had to be performed. The patient died soon afterward of treatment-refractory arrhythmias. The two other survivors experienced rapid recovery and an uncomplicated clinical course.

Impella 5.0-Treated Patients (n = 9)

The clinical course of 30-day survivors, as well as patients who had died at 30 days, is displayed in Table 4. In brief, two out of three survivors experienced rapid recovery and an uncomplicated clinical course. The third patient experienced a somewhat complicated clinical course after 5.0 removal, however, she was discharged home in good condition eventually as well. Six patients had died by 30 days, four of whom did not respond to 5.0 therapy, and in whom upgrade to a surgical left ventricle assist device was not a feasible option due to a variety of reasons. One patient died of a large stroke after several days of concomitant IABP and Impella support; another patient died due to septic shock.

Upgraded Patients (n = 8)

The indications for upgrade, and the subsequent clinical course, are displayed in Table 5. The decision for upgrade was driven by severe hypotension or a suboptimal cardiac output, despite Impella 2.5 support and inotropic therapy, in all patients except for one. Three out of eight patients were upgraded for severe hemodynamic instability within 6 hrs after 2.5 placement. Two other patients were upgraded between 6 and 48 hrs for persistent hemodynamic instability, despite stabilization in the acute setting. The three other patients deteriorated more slowly during their clinical course. The decision for upgrade in one of those patients was driven by an inability to wean from Impella 2.5 support without acute hemodynamic instability. Three out of eight patients survived through 30 days, one of whom could not be weaned from Impella 5.0 support and was therefore subsequently bridged to a HeartMate II surgical ventricular assist device, on which he survived for almost 2 yrs. The other two patients recovered after several days of Impella 5.0 support and were discharged home after several weeks, although the clinical course in one of them was complicated by limb ischemia and subsequent surgery. Five patients had died by 30 days due to a variety of causes, as detailed in Table 5. In two of those patients, the device had been explanted several days before.

DISCUSSION

Upon intention-to-treat comparison, no obvious differences seem to be present with regard to efficacy of initial 2.5 vs. initial 5.0 Impella treatment in STEMI patients presenting with profound CS requiring mechanical ventilation. However, three out of six patients who were initially treated with a 2.5 device and who survived at 30 days had been upgraded to a 5.0 device during their clinical course. Our results therefore suggest a more favorable clinical course in patients receiving 5.0 support, either as ini-

Table 2. Summary of the clinical course in patients who were initially treated with Impella 2.5 versus patients who received immediate Impella 5.0 support

Clinical Course	Impella 2.5 (n = 25)	Impella 5.0 (n = 9)	*p*
Total duration of support (hrs), median + interquartile range	50 (6–231)	129 (82–293)	.18
Upgraded to 5.0 device (%)	8 (32)	—	
Upgraded within 6 hrs (%)	3 (12)	—	
Upgraded between 6 and 48 hrs (%)	2 (8)	—	
Upgraded after 48 hrs (%)	3 (12)	—	
Status at 6 hrs			
Alive	20 (80)	9 (100)	.146
pH mean + SD[a]	7.29 ± 0.16	7.29 ± 0.11	.93
Mean arterial blood pressure >70 mm Hg (%)[b]	9 (45)	4 (50)	1.0
>1 inotropic agent (%)	15 (75)	6 (67)	.64
Mechanical ventilation (%)	17 (85)	9 (100)	.22
Hemodialysis treatment (%)	0 (0)	1 (11)	.13
Status at 48 hrs			
Alive	14 (56)	8 (89)	.077
pH (mean + SD)[c]	7.41 ± 0.06	7.39 ± 0.08	.56
Lactate (mean + SD)[d]	3.3 ± 1.1	2.8 ± 1.5	.48
Mean arterial blood pressure >70 mm Hg (%)[c]	6 (46)	4 (50)	.86
>1 inotropic agent (%)	8 (57)	6 (75)	.40
Mechanical ventilation (%)	7 (50)	6 (75)	.17
Hemodialysis treatment (%)	11 (78.6)	4 (50)	.26
Status at 30 days			
Alive	6 (24)	3 (33)	.586

[a]Data available in 19 and 9 patients, respectively; [b]data available in 18 and 8 patients, respectively; [c]data available in 13 and 8 patients, respectively; [d]data available in 10 and 5 patients, respectively.

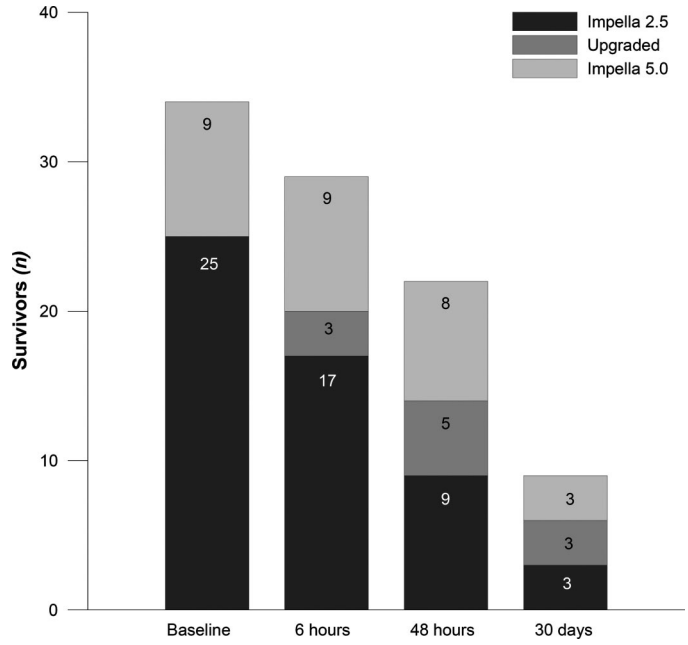

Figure 1. The number of survivors at baseline through 30-day follow-up is displayed per patient group. The reported 2.5 group consists of both the 2.5 and the upgraded patients, which are on display separately.

tial treatment or after initial stabilization with the 2.5 device.

Mechanical Circulatory Support for Cardiogenic Shock

Several devices for mechanical cardiac support have been in use for the treatment of CS. Beneficial results have been demonstrated in STEMI patients with CS who were treated with surgical ventricular assist devices (13, 14). However, the invasiveness of such devices precludes immediate placement upon presentation, which is especially important for patients presenting with STEMI. Several percutaneous assist systems have been developed, the most established of which is the IABP, although no beneficial effect on left ventricular ejection fraction or mortality could be demonstrated (5), despite its Class I guideline recommendation (4). Several percutaneous devices have been developed and studied in the setting of CS, including the extracorporeal membrane oxygenation and TandemHeart systems. Some experience has been reported on the usage of a percutaneous extracorporeal membrane oxygenation system for refractory postcardiotomy CS (15). The TandemHeart system has been evaluated in CS as well, in two randomized trials (16, 17). However, despite a favorable effect on hemodynamics, complication rate was high. As for both TandemHeart and extracorporeal membrane oxygenation, insertion procedures are complex and complication rates are high, so they may not be the preferred treatment in the setting of CS, especially in the setting of STEMI.

Impella System

A less invasive device is the Impella system, which was introduced in our institution in 2004 (7). In the experimental setting, Impella support has been demonstrated to reduce infarct size (18). Furthermore, it has been demonstrated to be easy to implant, safe, and feasible in elective high-risk percutaneous coronary intervention (8, 9) and in STEMI without CS (11). In 2003, Meyns et al (19) reported on the initial safety and feasibility experiences with the Impella system in six patients with CS after STEMI. Treatment led to a decrease in wedge pressure and blood lactate levels, as well as an increase in blood pressure and cardiac output. In the ISAR-SHOCK trial, Impella 2.5 support improved cardiac index at 30 mins after placement when compared to IABP in STEMI patients with CS (20). Thirty-day mortality in this trial was 46% in both 13 IABP- and 12 Impella-treated patients. However, apart from the ISAR-SHOCK trial, data on the usage of the Impella 2.5 in CS are scarce.

Although treatment with the Impella 2.5 may lead to an improvement in hemodynamic condition, the reported increase in cardiac output ranges from 0.5 to 1.0 L/min. Therefore, the Impella 2.5

Table 3. Per-patient description of the clinical course of Impella 2.5-treated patients

Age	Infarct-Related Artery	Gender	Hours on IABP	Hours on Impella 2.5	Time to Death (Days)	Clinical Course
Survivors at 30 days						
76	LAD	M	0	81	32	Several days after the Impella had been removed surgery was performed for severe limb ischemia. Postoperatively, the patient died of treatment-refractory arrhythmias
48	LAD	M	0	50	—	Recovery of clinical condition, uncomplicated clinical course
52	LAD	M	0	22	—	Rapid recovery of clinical condition, uncomplicated clinical course
Deceased at 30 days						
51	LM	M	1	19	1	Progressive hypotension over several hours despite high-dose norepinephrine, epinephrine, and Impella 2.5 support
64	LM	M	0	187	16	Sudden deterioration of clinical condition after device removal. The patient died due to stroke of unknown origin
62	LAD	M	193	192	8	Persistent hemodynamic instability without improvement despite several days of IABP and Impella 2.5 support as well as high-dose dobutamine, milrinone, and norepinephrine
57	LM	M	0	0.25	0	Despite revascularization, CPR, and Impella 2.5 insertion, there was no return of spontaneous circulation
51	LM	M	49	46	2	Progressive need for inotropic support despite IABP and Impella 2.5 treatment. Eventually, treatment-refractory bradycardia and cardiac arrest developed
39	LM	M	0	1	0	Rapid deterioration of metabolic conditions despite adequate revascularization, Impella 2.5 placement, and continuous CPR
51	LM	M	0	6	0	Persistent need for high-dose inotropic therapy, multiple episodes of CPR, and rapid development of massive pulmonary edema
63	LM	M	214	187	26	Pulmonary infection after device removal, complicated by rapid deterioration of left ventricular function
69	LAD	M	6	5	0	Rapid deterioration of clinical condition despite high-dose inotropic therapy and Impella 2.5 support after percutaneous coronary intervention
52	LAD	M	0	36	0	Sudden deterioration including pulmonary edema, ventricular fibrillation, and cardiac arrest after initial stabilization, despite Impella support and CPR
79	LAD	M	0	117	16	Respiratory insufficiency, sepsis, and multiorgan failure developed a few days after device removal
79	LM	M	0	6	0	Tortuous arterial trajectory blocked implantation of an Impella 5.0 device. Despite 2.5 support and high-dose inotropes, clinical condition deteriorated rapidly
50	LAD	M	0	2	0	Before an Impella 5.0 device could be implanted, acute severe treatment-refractory respiratory insufficiency developed
74	LM	Female	0	2	0	Tortuous arterial trajectory blocked implantation of an Impella 5.0 device. Despite 2.5 support and high-dose inotropes, clinical condition deteriorated rapidly

CPR, cardiopulmonary resuscitation; IABP, intra-aortic balloon pump; LAD, left anterior descending coronary artery; LM, left main coronary artery; M, male.

device is especially important for left ventricular (LV) unloading, which may promote myocardial recovery (11, 20, 21). The unloading effect of Impella 2.5 treatment was demonstrated in previous studies, demonstrating an immediate decrease in pulmonary capillary wedge pressure (11) and a decrease in end-diastolic LV wall stress (12). The Impella 5.0 device generally provides flow of about 4.0–4.5 L/min. Thus, it provides a substantially larger contribution to overall circulation and organ perfusion, in addition to the LV unloading effect. In our study, survival rates did not differ significantly between groups on intention-to-treat analysis. Nevertheless, a substantial proportion of 30-day survivors in the 2.5 group had been upgraded to the 5.0 device during treatment. Although survival rates vary among different studies, in our study, survival rates seem rather low. Potentially, our study represents a more severely ill patient population, which is reflected by the fact that most patients were already mechanically ventilated before the device was implanted, in addition to low pH and high lactate levels. An important observation was that patients who were initially treated with the 2.5 device could be successfully upgraded to the larger 5.0 device when 2.5 support was clinically insufficient. The decision on upgrade however, was influenced by many factors, including clinical judgment, the avail-

Table 4. Per-patient description of the clinical course of Impella 5.0-treated patients

Age	Infarct-Related Artery	Gender	Hours on IABP	Hours on Impella 5.0	Time to Death (Days)	Clinical Course
Survivors at 30 days						
65	Right coronary artery	F	56	175	—	Recovery after several days of support. Despite episodes of delirium and respiratory insufficiency, she was eventually discharged home in good clinical condition
46	LAD	M	0	129	—	Recovery after 5 days of Impella 5.0 support, uncomplicated clinical course
58	LM	F	0	95	—	Recovery after 4 days of Impella 5.0 support, uncomplicated clinical course
Deceased at 30 days						
73	Left circumflex coronary artery	M	167	339	13	Progressive deterioration of clinical condition due to sepsis
57	LAD	M	327	326	13	Depressed left ventricular function despite IABP, Impella 5.0, and high-dose inotropes. Sudden deterioration of neurologic condition due to large stroke
71	LM	M	69	68	3	Progressive deterioration of hemodynamic and respiratory condition over several days despite high-dose milrinone and norepinephrine in addition to IABP and Impella 5.0 support
58	LM	M	190	496	21	Inability to wean from Impella 5.0 support, scheduled for device exchange and eventual upgrade to a surgical left ventricular assist device. Subsequent rapid deterioration during the exchange procedure
73	LAD	M	0	126	5	Progressive deterioration of clinical condition over several days despite percutaneous coronary intervention, Impella 5.0 treatment, and high-dose norepinephrine, dobutamine, and epinephrine
46	LAD	F	0	12	1	Rapid deterioration of clinical condition despite Impella 5.0 support and high-dose dobutamine, milrinone, and norepinephrine

F, female; IABP, intra-aortic balloon pump; LAD, left anterior descending coronary artery; LM, left main coronary artery; M, male.

ability of cardiac surgery for Impella 5.0 implantation, and our experience over the years using Impella in these and other patient sets.

Clinical Implications

Our study represents our real-world experience that has been gained with the different types of the Impella system since its introduction in our institution in 2004. Our observations have led to a potential recommended strategy for the application of Impella treatment in profound CS. When considering the effects of the 2.5 and the 5.0 device, LV unloading alone vs. LV unloading combined with circulatory support, the preferred treatment for patients in profound CS would be the implantation of an Impella 5.0 device. Nevertheless, the instant availability of a cardiac surgery team to allow for Impella 5.0 implantation in the catheterization laboratory is an important issue. Therefore, the Impella 2.5 device may be initially used as a bridge-to-Impella 5.0, especially since a beneficial effect on brain perfusion has been demonstrated in the experimental setting (22). When applying our current strategy to patients in our study who received sole Impella 2.5 treatment, we concluded that in the deceased patients, depicted in Table 4, only two out of 14 patients would not have been eligible for an upgrade. In three out of 14, an upgrade was actually planned, but cancelled due to technical difficulties.

Study Limitations

First of all, the retrospective nature of this study is an important limitation. Since hemodynamic and laboratory measurements were performed according to clinical routine instead of a prespecified study protocol, some measures were not available for the complete study cohort. Another important limitation is the relatively small sample size. However, the number of STEMI patients treated with Impella was only six in the study by Meyns et al (19) and 12 in the ISAR-SHOCK trial. In the study by Granfeldt, nine patients with ischemic heart disease were included, without a clear statement on the presence of STEMI. Therefore, our cohort describes the largest experience to date with Impella in the setting of STEMI with both Impella devices throughout several years. Furthermore, the study population is highly selected. Since the study was not randomized, Impella 2.5- and 5.0-treated patients are not fully comparable, although no differences were apparent when comparing both groups. Duration of support with either pump varied widely, which also potentially induced selection bias. As our experience with the Impella device increased, immediate Impella 5.0 implantation was performed more often over time. As such, the comparison of the 2.5 and the 5.0 devices is influenced by this experience bias. Furthermore, a large proportion of patients in the Impella 2.5 group were upgraded to treatment with a more powerful support device. As the concept of upgrading has been developed through the past years, the decision for upgrade

Table 5. Per-patient description of clinical course on patients who were upgraded from Impella 2.5 to Impella 5.0

Age	Infarct-Related Artery	Gender	Hours on Intra-Aortic Balloon Pump	Hours on 2.5	Indication for Upgrade	Hours on 5.0	Time to Death (Days)	Clinical Course After Upgrade to 5.0
Survivors at 30 days								
57	LAD	M	168	210	Inability to wean from support after 9 days of Impella 2.5 treatment	698	711	Inability to wean from Impella 5.0 support, subsequent HeartMate II implantation as a bridge-to-transplant. Discharge home after several months. Died due to end-stage heart failure
61	Left main coronary artery	Female	82	81	Persistent hypotension despite dobutamine, milrinone, and norepinephrine treatment after 3 days of 2.5 support	320	—	Recovery of left ventricular function after several days of Impella 5.0 support. Discharge home after several weeks, despite severe limb ischemia for which surgery was performed
59	LAD	M	0	4	Persistent hypotension after PCI despite dobutamine and norepinephrine treatment	67	—	Recovery of left ventricular function after 3 days of Impella 5.0 support. Discharge home after 5 wks, resumed all former activities after 9 months
Deceased patients at 30 days								
59	LAD	M	0	22	Persistent hypotension despite high-dose milrinone and norepinephrine, after 1 day of 2.5 support	319	16	Progressive deterioration of clinical condition and development of acute bowel ischemia over several days, despite initial stabilization
57	LAD	M	20	20	Persistent hypotension despite high-dose dobutamine, milrinone, and norepinephrine, after 1 day of Impella 2.5 and intra-aortic balloon pump support	21	2	Sudden deterioration due to extensive myocardial bleeding and cardiac tamponade (not related to Impella on postmortem examination) after initial improvement during several hours of Impella 5.0 support
46	LAD	M	0	223	Persistent hypotension without signs of improvement despite high-dose dobutamine and milrinone after several days of Impella 2.5 support	101	21	Progressive electric instability and deterioration of clinical condition over several days. Eventually deceased due to treatment-refractory ventricular arrhythmias
52	LAD	M	0	1	Persistent hypotension and metabolic acidosis after PCI, despite Impella 2.5 support and treatment with high-dose inotropic agents	268	11	After 11 days of Impella 5.0 support, no signs of recovery. Further treatment or upgrade to a surgical left ventricular assist device was not considered feasible
63	Right coronary artery	M	0	1	Persistent hypotension and metabolic acidosis after PCI, despite Impella 2.5 support	336	14	After Impella 5.0 removal, an episode of severe treatment-refractory pulmonary edema occurred

LAD, left anterior descending coronary artery; M, male; PCI, percutaneous coronary intervention.

was experience-driven rather than protocol-defined.

Therefore, selection bias may play an important role since some of the patients who would have been eligible for upgrade according to our current standards did not receive this treatment.

CONCLUSION

In patients with severe and profound CS, Impella 5.0 treatment may be associated with improved survival when compared to patients treated with the Impella 2.5 device alone. Importantly, a substantial proportion of patients who were initially supported with the Impella 2.5 device were upgraded to Impella 5.0 support for unresponsiveness to treatment, which led to improved survival in those patients. Therefore, in STEMI patients presenting with profound CS, initial treatment with an Impella 2.5 device and subsequent upgrade to a 5.0 device is an acceptable treatment strategy, as well as immediate Impella 5.0 implantation.

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