ESC HEART FAILURE
ESC Heart Failure 2021; **8**: 3720–3725
Published online 17 August 2021 in Wiley Online Library (wileyonlinelibrary.com) **DOI:** 10.1002/ehf2.13512

ORIGINAL RESEARCH ARTICLE

A case series analysis on the clinical experience of Impella 5.5® at a large tertiary care centre

Peter J. Kennel[1†], Heidi Lumish[1†], Yuji Kaku[2], Justin Fried[1], Ajay J. Kirtane[1,3], Dimitri Karmpaliotis[1], Hiroo Takayama[2], Yoshifumi Naka[2], Gabriel Sayer[1], Nir Uriel[1], Koji Takeda[2] and Amirali Masoumi[1*]

[1]*Division of Cardiology, Columbia University Irving Medical Center/NewYork-Presbyterian Hospital, 161 Fort Washington Avenue, New York, NY 10032, USA;* [2]*Division of Cardiothoracic Surgery, NewYork-Presbyterian Hospital, New York, NY, USA; and* [3]*Division of Cardiology, Cardiovascular Research Foundation, New York, NY, USA*

Abstract

Aims We aimed to detail the early clinical experience with pVAD 5.5 at a large academic medical centre. Impella® 5.5 (Abiomed) is a temporary peripherally inserted left ventricular assist device (pVAD) used for the treatment of cardiogenic shock (CS). This system has several modifications aimed at improving deliverability and durability over the pVAD 5.0 system, but real-world experience with this device remains limited.

Methods and results We collected clinical and outcome data on all patients supported with pVAD 5.5 at our centre between February and December 2020, including procedural and device-related complications. Fourteen patients with pVAD 5.5 were included. Aetiology of CS was acute myocardial infarction (n = 6), decompensated heart failure (n = 6), suspected myocarditis (n = 1), and post-cardiotomy CS (n = 1). Four patients received pVAD 5.5 after being on inotropes alone, two were escalated from intra-aortic balloon pump, two were escalated from pVAD CP, and six patients were transitioned to pVAD 5.5 from extracorporeal membrane oxygenation. Median duration of pVAD 5.5 support was 12 (interquartile range 7, 25) days. Complications included axillary insertion site haematoma (n = 3), acute kidney injury (n = 3), severe thrombocytopenia (n = 1), and stroke (n = 1). No valve injury or limb complications occurred. Survival to device explant for recovery or transition to another therapy was 11/14 (79%) patients.

Conclusions In this early experience of the pVAD 5.5, procedural and device-related complications were observed but were manageable, and overall survival was high in this critically ill cohort, particularly when the device was used as a bridge to other therapies.

Keywords Impella® 5.5; pVAD; Cardiogenic shock; Mechanical circulatory support

Received: 4 May 2021; Revised: 9 June 2021; Accepted: 4 July 2021
**Correspondence to: Amirali Masoumi, MD, Assistant Professor of Medicine, Division of Cardiology, Columbia University Irving Medical Center/NewYork-Presbyterian Hospital, 161 Fort Washington Avenue, New York, NY 10032, USA. Tel: (212) 342-0444. Email: am4052@cumc.columbia.edu*
†These authors contributed equally.

Introduction

The Impella® 5.5 (Abiomed, Danvers, MA) percutaneous temporary left ventricular assist device (pVAD 5.5) received Food and Drug Administration pre-market approval in September 2019. The therapeutic concept of percutaneous trans-aortic temporary LVAD is left ventricular (LV) unloading to reduce myocardial workload and oxygen consumption to allow for cardiac recovery or to provide a bridge strategy to further advanced therapies. The pVAD 5.5 is intended for short-term use in the treatment of cardiogenic shock (CS) and can provide a peak flow rate of 6 L/min.[1] This axial flow pump is placed surgically via the axillary artery and has a more compact design and provides higher peak flow rates than the pVAD 5.0. Further design improvements include an overall shorter rigid length of motor and outlet and lack of a pigtail at the catheter tip. These modifications were designed to improve catheter manoeuvrability from the axillary approach and reduce the risk of cannula kinking and tethering in the LV cavity.

In a report of initial clinical outcomes for pVAD 5.5, survival on device support was excellent in a critically ill cohort and complications were rare.[2] Mechanistic data suggest a more favourable haemocompatibility profile for the pVAD

© 2021 The Authors. ESC Heart Failure published by John Wiley & Sons Ltd on behalf of European Society of Cardiology.
This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

5.5 as compared with a centrifugal cardiac assist system, with reduced haemolysis and platelet activation.[3] Furthermore, early data suggest that the more recently available pVAD 5.0 devices reduce haematologic complications.[4]

However, the clinical experience with this novel device is limited. Here, we report our clinical real-world experience with pVAD 5.5 at Columbia University Irving Medical Center, a tertiary medical centre with a large CS and mechanical circulatory support programme.

Methods

All patients who were supported with pVAD 5.5 at our centre between February 2020 and December 2020 were included in the study. Clinical and outcome data were obtained from retrospective review of electronic medical records. All patients had the first-generation pVAD 5.5 implanted. At our institution, the pVAD 5.5 is placed using a transthoracic technique. A vascular graft is anastomosed to the right axillary artery. A vascular sheath is then inserted into the graft. The pVAD 5.5 is advanced over a guidewire into the left ventricle. Placement is confirmed with fluoroscopy and transoesophageal echocardiography guidance prior to starting the pVAD. During the procedure, heparin is administered to maintain the activated clotting time $>$220 s, and subsequently, a heparin drip is administered to maintain partial thromboplastin time at 60–80 s.

The following device-related complications were analysed: haemolysis, thrombocytopenia, cerebrovascular accident, aortic valve injury, limb ischaemia, vascular complications, acute kidney injury (AKI), and bleeding. Haemolysis was defined as new low or undetectable haptoglobin level after pVAD 5.5 placement in patients with decreasing haemoglobin with no other more likely cause for anaemia (such as haematoma, immediately post-operatively) and laboratory values in conjunction with haemolysis (elevation in reticulocytes, lactate dehydrogenase, and unconjugated bilirubin). Severe thrombocytopenia was defined as platelets $<$ 50 000/μL after pVAD placement. Vascular complications were defined according to the Valve Academic Research Consortium-2 criteria,[5] AKI according to the Kidney Disease Improving Global Outcomes criteria,[6] and bleeding complications according to the Bleeding Academic Research criteria.[7] All patients were followed until device explantation for recovery, death, or transition to durable LVAD or heart transplantation. This study was approved by the Columbia University Irving Medical Center Institutional Review Board. Descriptive statistics are presented as mean ± standard deviation for continuous variables and counts with percentages for categorical variables. If continuous variables were not normally distributed, data are presented as median and interquartile range (IQR). The investigation conforms with the principles outlined in the Declaration of Helsinki.

Results

Baseline characteristics and transition to pVAD 5.5

Between February and December 2020, 14 patients with pVAD 5.5 were identified (synopsis, *Figure 1*). The median age was 60 (IQR 53–68) years, and 10 (71%) patients were male. All patients had an LV ejection fraction $\leq$ 30% (haemodynamic data, *Table 1*). Eight (57%) patients had at least moderate right ventricular dysfunction by transthoracic echocardiography (Supporting Information, *Table S1*). The aetiology of CS was acute myocardial infarction in seven (50%) cases, decompensated chronic heart failure (HF) in five (36%) cases, suspected acute myocarditis in one (7%) case, and post-cardiotomy CS in one (7%) case. Two patients in CS (14%) had the pVAD 5.5 placed for ventricular support during high-risk percutaneous coronary intervention, and in one of these patients, the device was removed the following day. Four (29%) patients were transitioned to pVAD 5.5 from inotropes alone, two (14%) from intra-aortic balloon pump (IABP), and two (14%) from Impella® CP percutaneous LVAD. Six (43%) patients were transitioned to pVAD 5.5 as a de-escalation from veno-arterial extracorporeal membrane oxygenation (VA-ECMO). In Patient 11, the Impella 5.5 was maintained in place after transition to VA-ECMO for LV unloading. Median duration of pVAD 5.5 support was 12 days (IQR 7–25) (case synopsis, *Table 2*).

Patient outcomes

Survival to device explant for recovery or transition to another advanced therapy was 12/14 (86%) (*Figure 1*, timeline). Two patients died of refractory CS while on pVAD 5.5 support, and one died shortly after pVAD 5.5 explantation following a stroke. Of the survivors to hospital discharge, one patient required escalation to surgically implantable biventricular support for refractory ventricular arrhythmias (followed by orthotopic heart transplantation), one required escalation to VA-ECMO and then surgically implantable biventricular support for refractory ventricular arrhythmias (followed by orthotopic heart transplantation), four patients were bridged to durable LVAD, two were bridged to heart transplantation, and three achieved ventricular recovery.

Figure 1 Timeline and events.

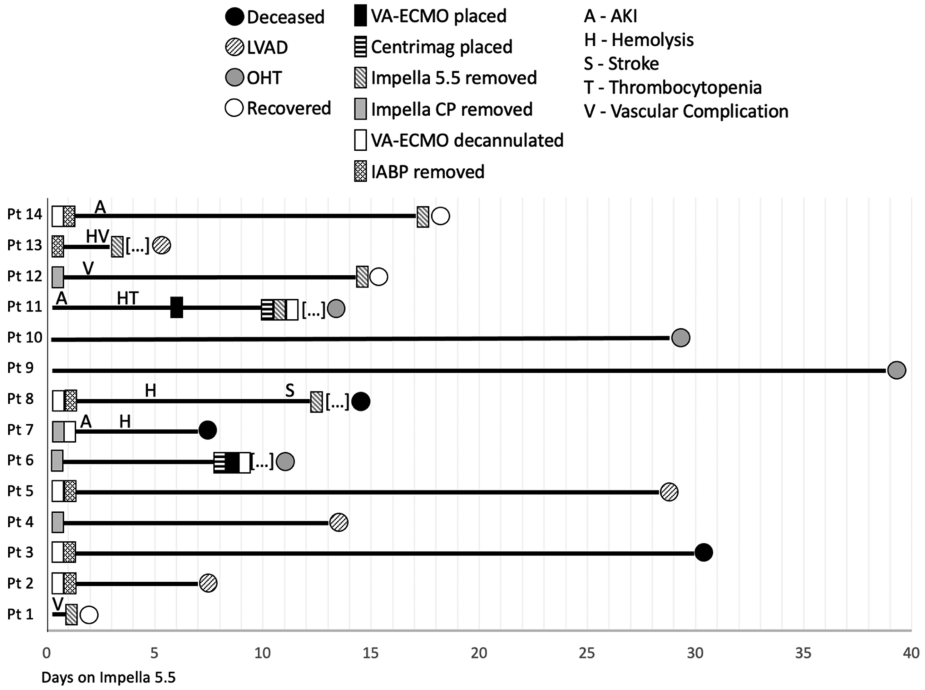

Table 1 Haemodynamics pre- and post-pVAD 5.5 placement

Patient		CVP (mmHg)	PAP (mmHg)	PCWP (mmHg)	PA sat (%)	CI (L/min/m^2)
1	Pre	22	78/34 (55)	41		1.4
	Post	4	33/14 (15)	16	61	2.7
2	Pre	16	65/33	35	31	1.2
	Post	5	23/11 (13)		66.6	3.4 (with VAD)
3	Pre	10	41/25 (32)	27	50	1.6
	Post	6	41/16 (25)		50.4	2.3
4	Pre	10	30/21 (25)	20	46.6	2.3 (on pVAD CP)
	Post		26 (mean)	20	60	
5	Pre	28	75/33 (49)	27	32	1.16
	Post	13	53/26 (36)	20	62	2.2
6	Pre					
	Post	8	25/12 (17)		64	
7	Pre	23	28/19 (24)	22	44	0.9
	Post	10	39/18 (25)			2.3
8	Pre		32/16			
	Post	8			59	2.5
9	Pre	8	64/31	40		3.1
	Post	2	33/11	12	71	
10	Pre	13	74/24 (52)	31	39.5	1.0
	Post	1	45/11 (21)	11		
11	Pre	6	30/20 (25)	22	70	1.95
	Post	11	19/15 (16)		80.5	
12	Pre		43/30	31		
	Post	12	24/5 (15)	10	61	2.74
13	Pre	32	61/45 (53)	45	40	1.2
	Post	23	59/36 (44)		57.7	
14	Pre	8	51/24 (38)	18	60	2.5
	Post	11	41/22 (29)		60	2.2

Table 2 Case synopsis

Patient	Age	Sex	HF aetiology	CPR	Indication for pVAD 5.5 placement	Time on support (days)	Outcome
1	67	M	ICM	No	pVAD-assisted high-risk PCI	1	Recovery
2	55	M	ICM	No	pVAD-assisted high-risk PCI	7	LVAD
3	68	M	ICM	Yes	Cardiogenic shock in the setting of delayed presentation anterior myocardial infarction	30	Deceased
4	73	M	ICM	No	Post-CABG cardiogenic shock, refractory to pVAD CP	13	LVAD
5	53	M	ICM	No	Bridge from VA-ECMO to LVAD in the setting of cardiogenic shock	28	LVAD
6	54	M	ICM	No	Bridge to CABG after STEMI	8	OHT
7	58	M	ICM	Yes	Transition off VA-ECMO after STEMI	7	Deceased
8	62	F	ICM	No	Post-CABG cardiogenic shock, transition off VA-ECMO	10	Deceased
9	32	F	NICM	No	Bridge to transplant for cardiogenic shock in the setting of possible influenza myocarditis	39	OHT
10	48	M	NICM	No	Bridge to transplant	29	OHT
11	69	F	Giant cell myocarditis	No	Cardiogenic shock due to myocarditis Left ventricular unloading while on VA-ECMO	10	OHT
12	63	F	ICM	No	Bridge to recovery after STEMI	15	Recovery
13	30	M	NICM	No	Bridge to LVAD for refractory cardiogenic shock	3	LVAD
14	73	M	ICM	No	Bridge to recovery from VA-ECMO after NSTEMI	17	Recovery

IABP, intra-aortic balloon pump; ICM, ischaemic cardiomyopathy; NICM, non-ischaemic cardiomyopathy; NSTEMI, non-ST-elevation myocardial infarction; OHT, orthotopic heart transplantation; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; VAD, ventricular assist device; VA-ECMO, veno-arterial extracorporeal membrane oxygenation.

Complication rates and management

Seven patients (50%) experienced at least one form of likely device-related complications (*Figure 1*). One patient had severe thrombocytopenia, three developed axillary haematomas, three had AKI, and one had a cardioembolic stroke with possible haemorrhagic conversion (Supporting Information, *Table S2*). Aortic valve injury, distal limb ischaemia, or other vascular complications did not occur. Of note, while haemolysis was suspected clinically in four patients, laboratory values were either inconclusive or haemolysis could not be unequivocally linked to the pVAD device (e.g. patients had low haptoglobin before pVAD 5.5 implant). Among the patients who developed axillary haematomas, one required bedside exploration with placement of additional sutures and two required exploration in the operating room. Two patients experienced complications requiring revision of pVAD 5.5 placement: in Patient 2, the pVAD 5.5 was entangled in the mitral subvalvular apparatus at the time of device placement and required removal and replacement. In Patient 13, the pVAD 5.5 migrated into the ascending aorta while in the intensive care unit and the patient developed a large and expanding axillary haematoma, necessitating device removal. The device was not replaced due to haemodynamic stability. Both of these patients were eventually discharged with durable LVAD (*Figure 1*). Regarding three cases of AKI, one patient required transient continuous veno-venous haemofiltration after pVAD placement due to anuria (Patient 7), one patient meet AKI criteria as per outside hospital (OSH) records (Patient 11), and one patient met KDIGO criteria by a transient rise in Cr after pVAD placement (Patient 14). Renal function in Patients 11 and 14 recovered, while Patient 7 died of refractory CS and was not a candidate for durable mechanical circulatory support or transplant. Our dataset is limited regarding the characterization of changes in haemodynamic parameters pre- vs. post-Impella 5.5 placement: while for some patients, haemodynamics (central venous pressure (CVP), pulmonary artery pressure (PAP), pulmonary capillary wedge pressure (PCWP), and pulmonary artery (PA) sat%) improved after device placement, we were unable to obtain these parameters for all patients in the cohort, mostly due to Impella 5.5 having been placed at outside hospitals and patients then having been transferred to our centre for further management.

Conclusions

In this case series, we describe the outcomes of pVAD 5.5 used for the management of CS at our tertiary care centre. More than 75% of the patients were successfully bridged to another advanced HF therapy (surgical LVAD, durable LVAD, or heart transplantation) or recovery. While complications occurred, most could be managed, and the most common serious complication was the development of pVAD site haematoma requiring surgical exploration. Two devices had

to be removed for procedural complications. Strokes occurred at a low rate, in only one patient in our cohort. None of the pVAD devices had to be removed due to concern for haemolysis.

Formal indications for the use of pVAD 5.5 are the treatment of ongoing CS caused by acute myocardial infarction, cardiac surgery, or cardiomyopathy, in patients with isolated LV failure that fails to respond to conventional therapies (i.e. pressors, inotropes, and IABP). pVAD has also been used as a de-escalation strategy from VA-ECMO towards durable LVAD or transplant, attempting to reduce complication rates and mobilize the patient.[8] Almost half of the patients in our cohort were de-escalated from VA-ECMO to pVAD 5.5, with overall favourable outcomes.

Known adverse events of pVAD devices are AKI, bleeding, cardioembolic events such as strokes, vascular and limb complications, haemolysis, and thrombocytopenia due to mechanical shearing, and aortic valve injury, among others.[9,10] A major access site complication rate of 7–15% has been reported.[11] Of note, the incidence of complications varies widely in the literature, likely due to differing experience with pVAD implantation and management across centres. Other case series report very low overall complication rates.[2] In previous versions of pVAD, design revisions, generally with larger French sizes and higher output, had favourable complication profiles compared with prior versions.[12] Overall, in our cohort, the complication rate was reasonably low, with access site haematomas and kidney injury being the most common adverse events. Vascular complications at the axillary insertion site occurred in three patients, requiring device removal in one patient due to an expanding axillary haematoma. In our experience, it has been quite rare to have significant haemolysis with pVAD 5.5.

In a recent study, Nersesian *et al*. report outcomes of patients supported with Impella 5 (63 patients) and 5.5 (seven patients) and concluded that in this cohort, an increased lactate level and cardiopulmonary resuscitation (CPR) before pVAD deployment were predictors of 30 days of survival.[13] In our cohort, only two patients were resuscitated before device placement, both patients presented with ST-elevation myocardial infarction, and both died after 7 and 30 days on Impella support, respectively. Of note, none of the patients in our cohort had elevated lactate levels at device implant, likely due to other mechanical circulatory support having been in place before pVAD 5.5 (mostly Impella CP or ECMO).

The maximum time on pVAD 5.5 indicated by the manufacturer is $\leq$14 days.[14] In clinical practice, while the experience with this most recent version of percutaneous temporary VADs remains limited, pVAD 5.0 and 5.5 have been reliably used for longer periods, with device malfunction occurring very rarely.[2,15] In particular, in patients where the device is deployed as a bridge to transplant or to durable LVAD, support times of well over 30 days have been reported.[2] Similarly, in our cohort, the device remained in place for around 30 days in four patients with favourable outcomes. This strategy has been established with previous pVAD versions, with overall excellent outcomes.[16] Therefore, axillary pVAD 5.5 placement, allowing for early mobilization and tailored therapy with titratable support, appears to be a feasible strategy for patients requiring a bridge to advanced HF therapy.[17]

This case series analysis summarizes the real-world experience with the new pVAD 5.5 percutaneous LVAD at a large tertiary care centre. In this early experience, procedural and device-related complications were observed but were manageable, and overall survival was high in this critically ill cohort, particularly when the device was used as a bridge to other therapies. Notwithstanding the need for surgical implantation, this redesigned trans-aortic temporary LVAD may become an increasingly important tool in the CS armamentarium as a bridge to recovery or definitive therapy in these critically ill patients.

Conflict of interest

D.K. reports honoraria from Boston Scientific and Abbott Vascular. D.K. holds equity from Saranas, Soundbite, and Traverse Vascular. A.J.K. reports institutional funding to Columbia University and/or Cardiovascular Research Foundation from Medtronic, Boston Scientific, Abbott Vascular, Abiomed, CSI, CathWorks, Siemens, Philips, and ReCor Medical. In addition to research grants, institutional funding includes fees paid to Columbia University and/or Cardiovascular Research Foundation for speaking engagements and/or consulting; personal: consulting: Neurotronic; and travel expenses/meals from Medtronic, Boston Scientific, Abbott Vascular, Abiomed, CSI, CathWorks, Siemens, Philips, ReCor Medical, Chiesi, OpSens, Zoll, and Regeneron. A.M. reports honoraria from Abiomed.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Echocardiographic parameters before and after Impella 5.5 Implant.
Table S2. Laboratory values before and after Impella 5.5 Implant.

References

1. First U.S. Patients Treated with Impella 5.5 with SmartAssist, a Minimally Invasive, Forward Flow Heart Pump| ABIOMED, Inc. https://investors.abiomed.com/news-releases/news-release-details/first-us-patients-treated-impella-55-smartassist-minimally (accessed date: 11 March 2021)
2. Ramzy D, Soltesz E, Anderson M. New surgical circulatory support system outcomes. *ASAIO J* 2020; **66**: 746–752.
3. Roka-Moiia Y, Li M, Ivich A, Muslmani S, Kern KB, Slepian MJ. Impella 5.5 versus Centrimag: a head-to-head comparison of device hemocompatibility. *ASAIO J* 2020; **66**: 1142–1151.
4. Castro L, Zipfel S, Braunsteiner J, Schaefer A, Sill B, Söffker G, Kluge S, Lubos E, Rybczinski M, Grahn H, Schrage B, Becher PM, Barten MJ, Westermann D, Blankenberg S, Reichenspurner H, Bernhardt AM. Switching to Impella 5.0 decreases need for transfusion in patients undergoing temporary mechanical circulatory support. *J Crit Care* 2020; **57**: 253–258.
5. Kappetein AP, Head SJ, Généreux P, Piazza N, van Mieghem NM, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, van Es G-A, Hahn RT, Kirtane AJ, Krucoff MW, Kodali S, Mack MJ, Mehran R, Rodés-Cabau J, Vranckx P, Webb JG, Windecker S, Serruys PW, Leon MB. Valve Academic Research Consortium (VARC)-2. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document (VARC-2). *Eur J Cardiothorac Surg* 2012; **42**: S45–S60.
6. KDIGO Clinical practice guideline for acute kidney injury.
7. Mehran R, Rao SV, Bhatt DL, Gibson CM, Caixeta A, Eikelboom J, Kaul S, Wiviott SD, Menon V, Nikolsky E, Serebruany V, Valgimigli M, Vranckx P, Taggart D, Sabik JF, Cutlip DE, Krucoff MW, Ohman EM, Steg PG, White H. Standardized bleeding definitions for cardiovascular clinical trials: a consensus report from the Bleeding Academic Research Consortium. *Circulation* 2011; **123**: 2736–2747.
8. Bertoldi LF, Pappalardo F, Lubos E, Grahn H, Rybczinski M, Barten MJ, Legros T, Bertoglio L, Schrage B, Westermann D, Lapenna E, Reichenspurner H, Bernhardt AM. Bridging INTERMACS 1 patients from VA-ECMO to LVAD via Impella 5.0: de-escalate and ambulate. *J Crit Care* 2020; **57**: 259–263.
9. Ali JM, Abu-Omar Y. Complications associated with mechanical circulatory support. *Ann Transl Med* 2020; **8**: 835–835.
10. Subramaniam AV, Barsness GW, Vallabhajosyula S, Vallabhajosyula S. Complications of temporary percutaneous mechanical circulatory support for cardiogenic shock: an appraisal of contemporary literature. *Cardiol Ther* 2019; **8**: 211–228.
11. Iannaccone M, Albani S, Giannini F, Colangelo S, Boccuzzi GG, Garbo R, Brilakis ES, D'ascenzo F, de Ferrari GM, Colombo A. Short term outcomes of Impella in cardiogenic shock: a review and meta-analysis of observational studies. *Int J Cardiol* 2020; **324**: 44–51.
12. Chen S, Paone D, Spellman L, Ranganath NK, Carillo JA, Gidea CG, Reyentovich A, Thompson CA, Razzouk L, Kon ZN, Moazami N, Smith DE. Comparison of device-specific adverse event profiles between Impella platforms. *J Card Surg* 2020; **35**: 3310–3316.
13. Nersesian G, Tschöpe C, Spillmann F, Gromann T, Roehrich L, Mueller M, Mulzer J, Starck C, Falk V, Schoenrath F, Potapov E. Prediction of survival of patients in cardiogenic shock treated by surgically implanted Impella 5+ short-term left ventricular assist device. *Interact Cardiovasc Thorac Surg* 2020; **31**: 475–482.
14. ABIOMED|Important Safety Information. https://www.abiomed.com/important-safety-information (accessed date: 11 March 2021)
15. Davila CD, Sharma S, Krishnamoorthy P, Rengifo-Moreno P, Palacios IF, O'Neill W, Kapur NK, Witzke CF. Prevalence and clinical correlates of extended mechanical support in patients undergoing high-risk percutaneous coronary intervention in current clinical practice: insights from the cVAD registry. *Cardiovasc Revasc Med* 2020; **21**: 342–347.
16. Seese L, Hickey G, Keebler ME, Mathier MA, Sultan I, Gleason TG, Toma C, Kilic A. Direct bridging to cardiac transplantation with the surgically implanted Impella 5.0 device. *Clin Transplant* 2020; **34**: e13818.
17. Chung JS, Emerson D, Ramzy D, Akhmerov A, Megna D, Esmailian F, Kobashigawa J, Cole RM, Moriguchi J, Trento A. A new paradigm in mechanical circulatory support: 100-patient experience. *Ann Thorac Surg* 2020; **109**: 1370–1377.