Journal of the American Heart Association

CONTEMPORARY REVIEW

Intra-Aortic Balloon Pump as a Bridge to Durable Left Ventricular Assist Device

Matthew A. Brown 🆔, MS; Farooq H. Sheikh 🆔, MD; Sara Ahmed, MD; Samer S. Najjar 🆔, MD; Ezequiel J. Molina, MD

ABSTRACT: Left ventricular assist devices (LVAD) are increasingly being used as destination therapy in patients with Stage D heart failure. It has been reported that a majority of patients who receive a durable LVAD (dLVAD) present in cardiogenic shock due to decompensated heart failure (ADHF-CS). As it stands, there is no consensus on the optimal management strategy for patients presenting with ADHF. Bridging with intra-aortic balloon pumps (IABPs) continues to be a therapeutic option in patients with hemodynamic instability due to cardiogenic shock. The majority of data regarding the use of IABP in cardiogenic shock come from studies in patients presenting with acute myocardial infarction with cardiogenic shock and demonstrates that there is no benefit of routine IABP use in this patient population. However, the role of IABPs as a bridge to dLVAD in ADHF-CS has yet to be determined. The hemodynamic changes seen in acute myocardial infarction with cardiogenic shock are known to be different and more acutely impaired than those presenting with ADHF-CS as evidenced by differences in pressure/volume loops. Thus, data should not be extrapolated across these 2 very different disease processes. The aim of this review is to describe results from contemporary studies examining the use of IABPs as a bridge to dLVAD in patients with ADHF-CS. Retrospective evidence from large registries suggests that the use of IABP as a bridge to dLVAD is feasible and safe when compared with other platforms of temporary mechanical circulatory support. However, there is currently a paucity of high-quality evidence examining this increasingly important clinical question.

Key Words: cardiac surgery ■ cardiomyopathy ■ heart failure ■ intra-aortic balloon pump ■ left ventricular assist device

After more than 40 years, intra-aortic balloon pumps (IABPs) remain an option for temporary mechanical circulatory support (MCS) in various populations of patients presenting with cardiogenic shock. Historically, the majority of IABP-related literature focuses on acute myocardial infarction complicated by cardiogenic shock (AMI-CS). Although the routine use of IABP in AMI-CS is no longer recommended based on findings from a number of trials over the past 30 years (Table 1), the utility of IABPs in other patient populations presenting with cardiogenic shock remains unclear.[1–7] One of these specific populations is represented by patients who are bridged to a durable left ventricular assist device (dLVAD) with the use of IABP.

Patients being evaluated for dLVAD implantation represent an invariably sick phenotype of whom the vast majority suffer from chronic heart failure.

According to the 2019 Society of Thoracic Surgeons INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) Annual Report, 53% of patients who received a dLVAD implanted in the years 2017 to 2018 presented with cardiogenic shock manifestations and were classified as INTERMACS Profiles 1 or 2 (Table 2).[8] Almost 35% of these patients were bridged to dLVAD with some form of temporary MCS; IABP was used in almost half of all patients bridged with MCS.[8] Bridging patients who present in cardiogenic shock with mechanical support devices allows for completion of the dLVAD candidacy workup while also stabilizing the patient and optimizing end-organ function in anticipation of dLVAD implantation. However, the optimal bridging strategy to dLVAD remains a question. The objective of this review is to discuss the existing evidence as it pertains to hemodynamic augmentation that supports

Nonstandard Abbreviations and Acronyms

ADHF-CS	acute decompensated heart failure complicated by cardiogenic shock
IABP	intra-aortic balloon pump
IMACS	ISHLT Mechanically Assisted Circulatory Support Registry
INTERMACS	Interagency Registry for Mechanically Assisted Circulatory Support
MCS	mechanical circulatory support

the use of IABP in cardiogenic shock due to acute decompensated chronic heart failure (ADHF-CS). Furthermore, we aim to investigate the clinical outcomes and adverse events associated with the use of IABP as a bridge to dLVAD.

HEMODYNAMIC AUGMENTATION WITH IABP IN CARDIOGENIC SHOCK DUE TO ACUTE DECOMPENSATED HEART FAILURE

IABPs consist of 2 main components: a balloon filled with a gas, most commonly helium, and a console used for operating the device. The balloon is deployed into the thoracic aorta where it inflates during diastole, leading to increased coronary and visceral perfusion pressures, and deflates during systole resulting in decreased afterload. In theory, these hemodynamic effects should be ideal for patients with cardiogenic shock. Surprisingly, this did not amount to a survival advantage in patients with AMI-CS.[3–7] However, AMI-CS and ADHF-CS represent entirely different disease processes. AMI-CS results from acute loss of myocardial contractility while also subject to multiple acute inflammatory mediators and endothelial activation. Pressure/volume loops in AMI-CS demonstrate an acute shift down and rightward. On the other hand, ADHF-CS has the benefit of long-standing compensation with ventricular remodeling

and upregulation of neurohormonal components leading to a much tamer shift in the pressure/volume loop.[9] Given the differences in phenotypes represented by AMI-CS and ADHF-CS, the response to MCS should not be extrapolated across populations. Unfortunately, there are few studies specifically examining the raw hemodynamic effects following IABP insertion in the ADHF-CS population.

In 2019, den Uil and colleagues described 32 patients in ADHF-CS without acute coronary syndrome who were randomized to either inotropes alone versus IABP. Patients in the IABP group were noted to have a greater improvement in cardiac power output and mixed venous oxygen saturation, and a greater relative reduction in NT-proBNP (N-terminal pro-B-type natriuretic peptide).[10] Fried and colleagues performed a retrospective observational study of hemodynamics in 132 patients who had an IABP placed for ADHF-CS.[11] Improvements in mean arterial pressure, cardiac output, cardiac index, and pulmonary artery pressures were noted following IABP implantation resulting in clinical stabilization in 74% of patients.[11] In 2019, Malick and colleagues published a retrospective observational analysis of hemodynamics in patients receiving IABP for either AMI-CS or ADHF-CS. In order to be included, heart failure patients must have carried the diagnosis of heart failure for at least 6 months. Of 205 patients included, 132 were in the acute decompensated heart failure group. Both groups had significant flow impairment at baseline with a mean (SD) cardiac output of 3.02 (±0.84) L/min and cardiac power index of 0.26 W/m² (±0.06 W/m²).[12] Additionally, patients in the ADHF-CS group had worse baseline mean (SD) left ventricular ejection fraction (18% [±8.9] versus 30.2% [±12.2]), higher pulmonary artery pressures, and lower systemic vascular resistance compared with the AMI group. Following placement of IABP, mean (SD) cardiac output augmentation for the ADHF-CS group was 0.58 L/min (±0.79) versus 0.12 L/min (±1.00) for the AMI group. This represents almost a 25% improvement in cardiac output from baseline for the acute decompensated heart failure group whereas the AMI group experienced less than a 10% improvement from baseline.[12] It can be hypothesized that the

Table 1.   Effect of IABP on Mortality in Acute Myocardial Infarction With Cardiogenic Shock Meta-Analysis[7]

Study/Subgroup	Year	IABP Group		Control Group		Odds Ratio
		n=	Deaths	n=	Deaths	
Ohman et al[6]	2005	30	8	27	9	0.73 (0.23–2.27)
Prondzinsky et al[3]	2010	19	7	21	6	1.46 (0.39–5.51)
Theile et al[4]	2012	300	119	298	123	0.94 (0.67–1.30)
Total		349	134	346	138	0.94 (0.69–1.28)

IABP indicates intra-aortic balloon pump.

Table 2. INTERMACS Profile Definitions

INTERMACS Patient Profile	Description
Level 1	Critical cardiogenic shock
Level 2	Progressive decline despite inotropes
Level 3	Stable but inotrope dependent
Level 4	Resting symptoms
Level 5	Exertion intolerant
Level 6	Exertion limited
Level 7	Advanced New York Heart Association Class III

INTERMACS indicates Interagency Registry for Mechanically Assisted Circulatory Support.

lack of survival benefit in patients with AMI-CS who received an IABP in the IABP-SHOCK II (Intraaortic Balloon Pump in Cardiogenic Shock II) and other trials can be attributed to a relatively inferior degree of hemodynamic improvement as noted by Malick and colleagues in their AMI cohort. Additionally, the contrasting hemodynamic responses among the 2 etiologies of cardiogenic shock examined by Malick and colleagues may be explained by the differences in shock pathophysiology described by Brener et al.[9]

ALTERNATIVE VASCULAR ACCESS SITES FOR IABP PLACEMENT

Insertion of IABPs can take place in the cardiac catherization lab, operating room, or at the bedside if necessary. Vascular access for placement has most commonly been via the femoral artery. Benefits of this approach include a large caliber target that in most cases can be easily accessed using ultrasound guidance. There are, however, 2 significant downsides to this approach: patients must remain in bed, unable to flex their hip for the duration of therapy and the risk of back-wall perforation of the femoral or iliac artery can result in development of a significant thigh or retroperitoneal hematoma.[13]

In recent years, alternative sites for vascular access have been explored including the subclavian and axillary arteries. The theoretical benefits of alternative vascular access sites include improved early patient mobility to improve overall physical condition before cardiac replacement therapy and to allow longer duration of IABP therapy free of infectious complications. Russo and colleagues were among the first to describe their experience with subclavian artery IABP insertion in 2012.[14] Over the course of 3 years they placed 20 IABPs in patients with end-stage heart failure via a graft sewn to the subclavian artery. This technique not only allowed for safe vascular access to the artery but also stabilized the device in place minimizing the risk of balloon displacement.[14] Out of

the 20 patients, 14 patients were bridged to transplant, 3 were bridged to recovery and had the IABP removed, 1 patient was bridged to a dLVAD, 1 patient was bridged to a biventricular assist device, and 1 patient remained with ongoing IABP 37 days into IABP therapy at the time of publication. No patients died while receiving subclavian artery IABP support.[14] In 2015, Tanaka and colleagues also explored the use of left subclavian artery access for IABP placement.[15] Eighty-eight patients with decompensated heart failure planned for dLVAD implantation, heart transplant, or recovery had IABP placed via left subclavian artery. This study found an increase in both the frequency and duration of ambulation and 90% of patients were able to receive their intended therapies.[15] The most recent innovation for subclavian artery IABPs is the NuPulseCV intravascular ventricular assist system (NuPulseCV, Inc.). This is a modified, more durable IABP that is inserted in the distal subclavian artery. This portable support system allows for increased patient mobility and the potential for a longer duration of therapy. A feasibility trial including 45 patients found that 80% of implanted patients were alive and free of cerebral vascular accident (CVA) at 6 months.[16] Patients were also noted to have improved 6-minute walk tests, 2-minute step tests, and Kansas City Cardiomyopathy Questionnaire scores.[16] The axillary artery has also been a target of interest for vascular access. Bhimaraj and colleagues described the use of percutaneous left axillary artery placement of IABP in 195 patients with advanced heart failure.[17] Success, defined as those who received a heart transplant or dLVAD, was noted in 133 (68%) of patients. This study is the largest to date describing this route of access and found percutaneous left axillary artery insertion to be a feasible strategy.[17]

ADVERSE EVENTS ASSOCIATED WITH THE USE OF IABP AS A BRIDGE TO DURABLE LVAD

IABPs are relatively simple devices compared with other temporary MCS devices such as the family of Impella devices (Abiomed, Danvers, MA), TandemHeart (Cardiac Assist, Inc; Pittsburgh, PA), CentriMag ventricular assist system (Abbott Laboratories, Abbott Park, IL), and extracorporeal membrane oxygenation (ECMO). Unfortunately, all forms of temporary MCS are associated with adverse events. The most common complications seen with IABP use are similar to the use of any indwelling arterial device. Registry-based studies examining IABP use in all patient populations found the following incidence of complications: limb ischemia

(as evidenced by reduced pulse) 2.1% to 3.1%, complete loss of pulse and/or amputation 0.5% to 0.9%, CVA 0.1% to 2.0%, access site hemorrhage 2.4% to 4.3%, severe bleed 0.8% to 6.9%, IABP failure 1.2% to 3.6%, IABP-related death 0.05% to 0.1%, and any complication 5.4% to 13.1%.[18] Observational and comparative studies examining complication rates of IABP versus other types of MCS have generally demonstrated equal or better complication rates in favor of IABP.[19–22]

Several studies have explored adverse events associated with IABP use specifically in the setting of bridging to dLVAD. The IMACS (International Registry for Mechanical Circulatory Support) registry was examined for short- and long-term adverse events following the use of temporary MCS before dLVAD placement; IABP, ECMO, and control cohorts were compared The adverse events examined were hemorrhagic stroke (hCVA), ischemic stroke (iCVA), and bleeding.[23] These events were measured in events/100 patient months. At 3 postoperative months, ECMO had the most adverse events (hCVA 1.6, iCVA 2.8, bleeding 19) compared with IABP (hCVA 1.5, iCVA 1.5, and bleeding 17.3) and those not requiring temporary MCS before dLVAD (hCVA 1.1, iCVA 1.2, and bleeding 13.2).[23] The significant problem with this kind of analysis is that it does not include patients who developed serious adverse events and became ineligible for dLVAD therapy.

An INTERMACS registry analysis of 7112 patients implanted from 2012 to 2015 evaluated risk factors for stroke.[24] Stroke was detected in 752 patients with a calculated incidence of 0.123 strokes per patient-year. Pre-dLVAD IABP was found to be an independent risk factor for stroke (hazard ratio [HR], 1.21; 95% CI, 1.01–1.46; P=0.043).[24] However, authors did not discuss the temporality of the strokes in relation to the IABP insertion and thus no causality can be drawn from this finding. Other risk factors included female sex, preimplant systolic blood pressure, and heparin-induced thrombocytopenia.[24] In 2020, an infection-related analysis was performed on the data collected in the MOMENTUM 3 (Multicenter Study of MagLev Technology in Patients Undergoing Mechanical Circulatory Support Therapy with HeartMate 3) trial in which 1020 patients were implanted with either the HeartMate 3 (n=515) or the HeartMate II (n=505).[25] The total number of infections was tallied at the 2-year interval. The HeartMate 3 cohort was noted to have 634 infections versus 579 in the HeartMate II group. IABP was noted to be an independent predictor of major infection (HR, 1.33; 95% CI, 1.06–1.68; P=0.02) as well as female sex, preimplant history of cardiac surgery, and body mass index of 30 or greater.[25] Survival at 2-year post-dLVAD for those with infection was significantly worse compared with those without infection (73.6% versus 84.8%,

P<0.001). However, of the 141 patients who had died of infection, most patients who had infection died from other causes such as right heart failure (25%), stroke (17%), and other (38%).[25] Only 3 of 141 patients who died had a device-related infection. It should be noted that authors did not define the nature of these infections such as pre-dLVAD, perioperative, or if they occurred at some interval postoperative visit. Infections that are not directly associated with the IABP such as pneumonia are unlikely related to the IABP itself and probably more accurately reflect the sicker phenotype of a patient requiring mechanical circulatory support.

In an INTERMACS registry analysis published in 2018, 433 patients bridged to dLVAD with IABP were compared with 2013 patients not bridged with MCS. It was found that bleeding events were significantly higher in the IABP group at 7 days post-dLVAD implantation (17.3% versus 12.1%, P=0.003).[26] However, a 2016 retrospective cohort study comparing 10 patients bridged to dLVAD with IABP with 16 not bridged found no significant difference in transfusion requirements, minimum hematocrit, or minimum platelet counts.[26] It is clear that definitive conclusions cannot be made with such a small sample size, thus reiterating the need for larger trials or registry data extraction looking at this specific complication.

The data comparing complication rates and adverse events of temporary support devices in this patient population are not robust. From the data that are available, it cannot be argued one way or another whether the complication rates associated with IABP use are justified because the data supporting the benefits of IABP use as a bridge to dLVAD are also not strong. Additionally, patients who are deemed sick enough to require IABP may in themselves represent a population at risk for more adverse events such as infection and bleeding that may be independent of the actual device. Given the relative safety and simplicity of IABPs, it may not be unreasonable to initiate temporary mechanical support with IABP and upgrade to a more complex temporary device either as a replacement or in combination. Only large randomized trials comparing IABP with other devices and medical management would be able to conclusively demonstrate the rate of adverse events associated with each bridging strategy. Unfortunately, the majority of data currently available are derived from large registries that are known to be affected by selection bias as well as other forms of bias such as confounding and channeling bias.

OUTCOMES IN PATIENTS BRIDGED TO DURABLE LVAD WITH IABP

Temporary MCS such as IABP is often used as a bridge to dLVAD in patients unsustainable on

inotropes alone. Although IABP has been shown to improve hemodynamic and laboratory indices in patients with decompensated heart failure, there is a paucity of prospective data evaluating the survival benefit when IABP is used as a bridge to dLVAD (Table 3).[10–12]

A 2020 study of the IMACS registry represents perhaps the single best data set available. This study reviewed survival of 3901 patients bridged to dLVAD with IABP, 1138 with ECMO, and 595 patients with other types of temporary MCS such as Impella compared with a group of 8131 INTERMACS Profile 1 to 3 patients who were not bridged with temporary MCS. Survival of the nonbridged group at 1 and 48 months was 95% and 55% respectively compared with 93% and 51% for the IABP group, 82% and 44% for the ECMO group, and 92% and 52% for the other temporary support group.[27] It is worth noting that the overwhelming majority of those bridged with ECMO in this study, 883 of 1138 (77.6%), were INTERMACS Profile 1 compared with just 1185 (30.4%) for IABP, 268 (45.2%) for other types of temporary mechanical MCS, and 419 (5.3%) of those who did not receive any form of mechanical support pre-dLVAD.[27] However, when strictly looking at survival of INTERMACS Profile 1 patients based on temporary support strategy, survival at 1 and 48 months was 90.5% and 48.6% respectively for IABP, 82.3% and 41% for ECMO, and 93.2% and 47% for other forms of temporary MCS compared with patients with no temporary MCS who registered survival of 88.9% and 52.7% at 1 and 48 months respectively.[27]

Because of the lack of randomization in studies such as this, significant patient selection bias for the use of each technology cannot be eliminated. However, propensity matching was performed in the IMACS study for INTERMACS Profile 1 patients comparing 558 patients with pre-dLVAD ECMO to 558

Table 3. Select Studies of Outcomes and Adverse Effects of IABP Use as a Bridge to LVAD

Authors [Reference List]	Year	Study Design	Control (n=)	IABP (n=)	Findings
Hernandez-Montfort JA et al [27]	2020	Retrospective cohort with propensity matched analysis	8131 patients without any form of pre-operative MCS	3901	IABP-group survival at 1 and 48 mo were 93% and 51% respectively compared with 95% and 55% for those without preoperative MCS (*P*<0.0001). Propensity matching comparing those who received ECMO or IABP as preoperative MCS showed ECMO had higher hazard affecting early survival (HR, 1.65; *P*<0.01)
Kurihara C et al [28]	2018	Retrospective cohort with subgroups compared using univariate analysis	257 patients without any form of pre-operative MCS	172	Survival with pre-VAD IABP at 1, 6, 12, and 24 mo were 87.7%, 78.5%, 73.3%, and 65.1% respectively compared with the control group at 94.2%, 87.2%, 79.4%, and 72%. Overall *P* value and 24-mo *P* value were reported at 0.71 and 0.11 respectively suggesting no significant difference in survival. The only pre-VAD device associated with significant decreased survival was venoarterial-extracorporeal membrane oxygenation
Devore AD et al [26]	2018	Retrospective cohort with propensity matched analysis	2013 patients without any form of pre-operative MCS	433	Patients in the IABP group were more likely to have worse renal function, worse liver function tests, more right ventricular dysfunction, and more likely to have a history of cardiac arrest during hospitalization compared with controls before VAD implantation. 30-d outcomes for controls vs the IABP group were as follows: Right heart failure (11.6% vs 11.8%, *P*=0.94), hepatic dysfunction (1.3% vs 2.6%, *P*=0.07), renal dysfunction (5.3% vs 7.4%, *P*=0.08), and all-cause mortality (3.6% vs 5.1%, *P*=0.13). More bleeding was noted in the IABP group at 7 d (12.1% vs 17.3%, *P*=0.003).
Morici N et al [29]	2018	Phase II, prospective Simon 2-stage	N/A	17	21 patients survived to at least 60 d. LVAD was placed in 13 total patients and all of them survived to 60 d. Of the 17 patients who received IABP, 10 had LVAD placement, 2 had heart transplant, 2 recovered, and 3 died
Tanaka A et al [15]	2015	Retrospective observational	N/A	88	Study of subclavian artery access for IABP. 58 of the intended 61 patients bridged to transplant, all 21 patients bridged to mechanical circulatory support, and 3 of 6 patients recovered. Eighty-four patients (95.5%) ambulated more than 3 times a day. Two-minute step test demonstrated significant improvement, from 50±9 steps to 90±23 steps (n=16, *P*<0.001). 90% of patients received their intended therapy. Complications included IABP exchange (n=23), IABP reposition (n=3), re-exploration (n=6), CVA (n=2), and transient brachial plexus injury (n=2)
Ton VK et al [23]	2020	Retrospective cohort	7879 without any form of preoperative MCS	3901	At <3 postoperative months, there were more events (measured in events/patient month) in the IABP group (bleeding=17.3, hCVA=1.5, iCVA=1.5) vs control (bleeding=13.2, hCVA=1.1, iCVA=1.2). For all comparisons *P*<0.05. At >3 postoperative months, there were no differences in events between the 2 groups

CVA indicates cerebral vascular accident; hCVA, hemorrhagic cerebral vascular accident; IABP, intra-aortic balloon pump; iCVA, ischemic cerebral vascular accident; LVAD, left ventricular assist device; MCS, mechanical circulatory support; and VAD, ventricular assist device.

patients with pre-dLVAD IABP and 350 patients with pre-dLVAD ECMO to 350 patients requiring some other form of pre-dLVAD circulatory support. This propensity matching found that patients with pre-dLVAD ECMO had higher mortality hazard compared with IABP (HR, 1.65; P<0.01) and the group of other temporary MCS (HR, 1.80; P<0.01).[27] Additionally, patients who had pre-dLVAD ECMO were more likely to need biventricular support and had a longer post-dLVAD implantation intensive care unit course.[27]

The longitudinal survival noted in the IMACS registry affirmed the findings of a 2018 single-center retrospective cohort. This study included INTERMACS 1 to 3 patients receiving a dLVAD between the years 2003 and 2016 and found no statistically significant difference in 24-month survival in the IABP group compared with those without temporary MCS (65.1% versus 72%, P=0.11).[28] Survival at 1, 6, and 12 months were also found to not be significantly different (P=0.71).[28] The only device noted to have a significantly decreased survival was venoarterial ECMO. The difference in survival noted in this study was comparable to the IMACS registry, which reported survival at 24 months of 68.5% for IABP and 72.5% for those without temporary pre-dLVAD MCS.[27,28] An INTERMACS registry analysis was published in 2018 examining patients who had IABP placed within 48 hours of dLVAD. A group of 433 patients had IABP placed within 48 hours of dLVAD and were compared with 2013 patients who did not. Results of this retrospective cohort study found that patients with pre-dLVAD IABP were more likely to have renal dysfunction, hepatic dysfunction, right ventricular dysfunction, and cardiac arrest during the index dLVAD hospitalization compared with those without pre-dLVAD IABP.[26] However, at the 30-day mark, there was no difference in any of these metrics including all-cause mortality (IABP 5.1% versus 3.6%, P=0.13).[26] Findings of this study suggest the IABP group were sicker patients at the time of dLVAD implantation yet had no difference in 30-day survival. It must be mentioned that this study is lacking long-term follow-up.

A retrospective cohort study by Fried et al published in 2020 reviewed 165 consecutive patients who had the HeartMate 3 (Abbott Labs, Chicago, IL) implanted from November 2014 to July 2019. Sixty-nine patients were bridged to dLVAD using MCS with 55 of them using IABP, 6 using ECMO plus IABP, 3 using ECMO alone, 3 using a peripheral ventricular assist device alone, and 2 using ECMO plus a peripheral ventricular assist device.[30] Authors found that there was no difference in survival at 1 year between all patients using any of pre-dLVAD MCS and those who did not (90.3% versus 89.5%, P=0.80).[30] Patients who received MCS before dLVAD were younger and had represented more severe INTERMACS Profiles (1.71 versus 2.67, P<0.01).[29] Survival based on specific bridging strategy was not assessed.

The 2018 Altshock trial represents the only prospective study examining survival for patients bridged to dLVAD with IABP. This study was a Phase II, Prospective Simon 2-Stage design involving a decision-making algorithm where patients who presented with cardiogenic shock would progress down different pathways of escalated care depending on whether they reached different time-related targets.[29] For example, target 1 required patients to have at least 6 of the following 9 markers by 4 hours or they would have an IABP placed and/or mechanical ventilation added: heart rate 60 to 130 beats per minute, mean arterial pressure >65 mm Hg, mixed venous oxygen saturation >60%, partial pressure of oxygen >60 mm Hg, trend of declining lactate, respiratory rate <30 per minute, urine output of at least 0.5 mL/kg per hour, epinephrine dose <0.07 μg/kg per minute, and reduction of admission central venous pressure by at least 20%. A second target also existed at 48 hours with the addition of wedge pressure of <18 or E/E′ <14.[29] Failure to meet the second target would require patients to be placed on venoarterial ECMO support. In total, 21 of 24 (87.5%) of patients survived to at least 60 days. IABP was placed in 17 patients; only 1 patient required upgrade to ECMO following IABP for failure to achieve target 2. Ten of the 17 patients who received IABP underwent subsequent dLVAD implantation. All patients who had a dLVAD placed survived to at least 60 days. Of the remaining 7 patients who had an IABP placed but no dLVAD, 2 had a heart transplant, 2 recovered without requiring long-term support or heart transplantation, and 3 did not survive to definitive therapy.[29] This study was limited by a sample size of only 17 patients undergoing IABP insertion (10 of whom received a dLVAD) and by lack of long-term follow-up.

The existing literature suggests that selected INTERMACS Profile 1 to 2 patients bridged to dLVAD with IABP may enjoy comparable survival to those not requiring temporary mechanical support pre-dLVAD. The literature also suggests that IABP use is associated with better survival when compared with venoarterial ECMO in this patient population. Unfortunately, much of what is known about the survival in this patient population when IABP is used as a bridge to dLVAD is from retrospective studies and registry-extracted data. These methods of data collection do not provide the appropriate level of nuance required to understand why a particular patient did better with 1 device over another or with no temporary device at all. To best answer the question as to the efficacy of IABP as a bridge to dLVAD, large, sufficiently powered randomized trials comparing IABP

to other devices and controls must be performed in an excruciatingly meticulous fashion to avoid bias. Developing a sufficiently powered prospective study to answer a question of this magnitude is surely challenging as it often requires the coordination of multiple centers and a time interval allowing for not only subject enrollment but long-term follow-up.

Survival following dLVAD implantation is not the only indicator of the success of a bridging strategy. Theoretically, once a patient gets to the destination therapy, the bridging strategy becomes somewhat irrelevant. Other questions related to how effective the bridging strategy is at getting patients from their shock state at presentation to the operating room for device implantation must be answered. For example, an important aspect of bridging is how effectively this strategy corrects end-organ dysfunction in order to allow for timely dLVAD implantation before the development of additional complications. Furthermore, it is currently unknown what percentage of patients never become dLVAD candidates despite IABP bridging, what complications they develop and what their final outcomes are. Unfortunately, the available literature does not address questions of this nature. Future studies should focus on these important questions in addition to survival post-dLVAD implantation to truly evaluate the effectiveness of IABP as a bridging strategy compared with other devices and medical therapies.

FUTURE CONSIDERATIONS

As with any rapidly evolving field, the literature never sufficiently answers every possible clinical question. The gap in knowledge regarding the benefits of IABP as a bridging strategy to dLVAD remains prominent. There is a lack of randomized controlled trials comparing different strategies including IABP bridge versus other temporary devices versus a medical control group. The ideal initial randomized controlled trial should compare medical therapy versus IABP bridge to dLVAD. It should be an adequately powered multicenter study to minimize institutional bias. As mentioned in the previous section, survival post-dLVAD alone may not be the best indicator of bridging success to be investigated. Therefore, other important outcomes that should be investigated include the percentage of patients who actually transition to dLVAD therapy, effectiveness and rate at which end-organ dysfunction resolves, incidence of adverse events, and the rate at which the IABP bridging strategy needs to be upgraded to more robust mechanical support. Cost-effectiveness should also be investigated. The Altshock-2 Trial, an ongoing Italian study, may provide some of these answers.

This is a randomized controlled trial evaluating the use of IABP in patients with acute decompensated heart failure complicated by cardiogenic shock. In this study, an IABP is to be placed within 6 hours of onset of cardiogenic shock. Primary outcomes include successful bridge to heart transplant or dLVAD.[31]

CONCLUSIONS

IABP technology is a relatively less complex and more cost-effective option for temporary MCS support compared with other device platforms. However, the utility of IABP as a bridging strategy to dLVAD remains in question. The available evidence supporting the benefits of IABP use in patients with non-ACS related ADHF-CS is largely limited to retrospective observational data procured from registries which are subject to numerous biases. These studies suggest that using IABP is not only a feasible but also an effective temporary support strategy in this patient population as evidenced by comparable survival at both short- and long-term intervals. Additionally, retrospective data demonstrate some degree of improvement in hemodynamics following IABP placement in patients with decompensated heart failure. Adequately powered randomized controlled trials are currently missing. These studies are required to confirm a survival benefit currently inferred by the available retrospective literature. Moreover, they are also needed to explore other important metrics of success that demonstrate that IABP is an effective bridging strategy in this patient population including rate of reversal of end-organ dysfunction, incidence of adverse events and the rate at which patients become candidates for dLVAD therapy.

ARTICLE INFORMATION

Affiliations

Georgetown University School of Medicine, Washington, DC (M.A.B., F.H.S., S.S.N., E.J.M.); MedStar Washington Hospital Center, Washington, DC (F.H.S., S.A., S.S.N., E.J.M.); and MedStar Heart and Vascular Institute, Washington, DC (F.H.S., S.S.N., E.J.M.).

Disclosures

None.

REFERENCES

1. van Diepen S, Katz JN, Albert NM, Henry TD, Jacobs AK, Kapur NK, Kilic A, Menon V, Ohman EM, Sweitzer NK, et al. Contemporary management of cardiogenic shock: a scientific statement from the American Heart Association. *Circulation.* 2017;136:e232–e268. DOI: 10.1161/CIR.0000000000000525.
2. Patrick T, Kushner FG, Ascheim DD, Casey DE Jr, Chung MK, de Lemos JA, Ettinger SM, Fang JC, Fesmire FM, Franklin BA, et al. ACCF/AHA guideline for the management of ST-elevation myocardial infarction:

a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2013;127:e362–e425. DOI: 10.1161/CIR.0b013e3182742cf6.

3. Prondzinsky R, Lemm H, Swyter M, Wegener N, Unverzagt S, Carter JM, Russ M, Schlitt A, Buerke U, Christoph A, et al. Intra-aortic balloon counterpulsation in patients with acute myocardial infarction complicated by cardiogenic shock: the prospective, randomized IABP SHOCK Trial for attenuation of multiorgan dysfunction syndrome. *Crit Care Med*. 2010;38:152–160. DOI: 10.1097/CCM.0b013e3181b78671.

4. Thiele H, Zeymer U, Neumann F-J, Ferenc M, Olbrich H-G, Hausleiter J, Richardt G, Hennersdorf M, Empen K, Fuernau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. *N Engl J Med*. 2012;367:1287–1296. DOI: 10.1056/NEJMoa1208410.

5. Thiele H, Zeymer U, Thelemann N, Neumann FJ, Hausleiter J, Abdel-Wahab M, Meyer-Sarael R, Fuernau G, Eitel I, Hambrecht R, et al. Intraaortic balloon pump in cardiogenic shock complicating acute myocardial infarction: long-term 6-year outcome of the randomized IABP-SHOCK II trial. *Circulation*. 2019;139:395–403. DOI: 10.1161/CIRCULATIONAHA.118.038201.

6. Magnus Ohman E, Nanas J, Stomel RJ, Leesar MA, Nielsen DWT, O'Dea D, Rogers FJ, Harber D, Hudson MP, Fraulo E, et al. Thrombolysis and counterpulsation to improve survival in myocardial infarction complicated by hypotension and suspected cardiogenic shock or heart failure: results of the TACTICS Trial. *J Thromb Thrombolysis*. 2005;19:33–39. DOI: 10.1007/s11239-005-0938-0.

7. Ahmad Y, Sen S, Shun-shin MJ, Ouyang J, Finegold JA, Al-Lamee RK, Davies JE, Cole GE, Francis DP. Intra-aortic balloon pump therapy for acute myocardial infarction: a meta-analysis. *JAMA Intern Med*. 2015;175:931–939. DOI: 10.1001/jamainternmed.2015.0569.

8. Teuteberg JJ, Cleveland JC, Cowger J, Higgins RS, Goldstein DJ, Keebler M, Kirklin JK, Myers SL, Salerno CT, Stehlik J, et al. The Society of Thoracic Surgeons Intermacs 2019 annual report: the changing landscape of devices and indications. *Ann Thorac Surg*. 2020;109:649–660. DOI: 10.1016/j.athoracsur.2019.12.005.

9. Brener MI, Rosenblum HR, Burkhoff D. Pathophysiology and advanced hemodynamic assessment of cardiogenic shock. *Methodist Debakey Cardiovasc J*. 2020;16:7–15.

10. den Uil CA, Van Mieghem NM, Bastos MB, Jewbali LS, Lenzen MJ, Engstrom AE, Bunge JJH, Brugts JJ, Manintveld OC, Daemen J, et al. Primary intra-aortic balloon support versus inotropes for decompensated heart failure and low output: a randomised trial. *EuroIntervention*. 2019;15:586–593. DOI: 10.4244/EIJ-D-19-00254.

11. Fried JA, Nair A, Takeda K, Clerkin K, Topkara VK, Masoumi A, Yuzefpolskaya M, Takayama H, Naka Y, Burkhoff D, et al. Clinical and hemodynamic effects of intra-aortic balloon pump therapy in chronic heart failure patients with cardiogenic shock. *J Heart Lung Transplant*. 2018;37:1313–1321. DOI: 10.1016/j.healun.2018.03.011.

12. Malick W, Fried JA, Masoumi A, Nair A, Zuver A, Huang A, Haythe J, Farr M, Rabbani L, Karmpaliotis D, et al. Comparison of the hemodynamic response to intra-aortic balloon counterpulsation in patients with cardiogenic shock resulting from acute myocardial infarction versus acute decompensated heart failure. *Am J Cardiol*. 2019;124:1947–1953. DOI: 10.1016/j.amjcard.2019.09.016.

13. Bojar RM. *Manual of Perioperative Care in Adult Cardiac Surgery*. 5th ed. Hoboken, NJ: Wiley-Blackwell; 2011.

14. Russo MJ, Jeevanandam V, Stepney J, Merlo A, Johnson EM, Malyala R, Raman J. Intra-aortic balloon pump inserted through the subclavian artery: a minimally invasive approach to mechanical support in the ambulatory end-stage heart failure patient. *J Thorac Cardiovasc Surg*. 2012;144:951–955. DOI: 10.1016/j.jtcvs.2012.03.007.

15. Tanaka A, Tuladhar SM, Onsager D, Asfaw Z, Ota T, Juricek C, Lahart M, Lonchyna VA, Kim G, Fedson S, et al. The subclavian intraaortic balloon pump: a compelling bridge device for advanced heart failure. *Ann Thorac Surg*. 2015;100:2151–2157. DOI: 10.1016/j.athoracsur.2015.05.087.

16. Uriel N, Jeevanandam V, Imamura T, Onsager D, Song T, Ota T, Juricek C, Combs P, Lammy T, Patel-Ramen S, et al. Clinical outcomes and quality of life with an ambulatory counterpulsation pump in advanced heart failure patients: results of the multicenter feasibility trial. *Circ Heart Fail*. 2020;13:e006666. DOI: 10.1161/CIRCHEARTFAILURE.119.006666.

17. Bhimaraj A, Agrawal T, Duran A, Tamimi O, Amione-Guerra J, Trachtenberg B, Guha A, Hussain I, Kim JU, Kassi M, et al. Percutaneous left axillary artery placement of intra-aortic balloon pump in advanced heart failure patients. *JACC Heart Fail*. 2020;8:313–323. DOI: 10.1016/j.jchf.2020.01.011.

18. Patterson T, Perera D, Redwood SR. Intra-aortic balloon pump for high-risk percutaneous coronary intervention. *Circ Cardiovasc Interv*. 2014;7:712–720. DOI: 10.1161/CIRCINTERVENTIONS.114.001258.

19. Thiele H, Jobs A, Ouweneel DM, Henriques JP, Seyfarth M, Desch S, Eitel I, Poss J, Fuernau G, de Waha S. Percutaneous short-term active mechanical support devices in cardiogenic shock: a systematic review and collaborative meta-analysis of randomized trials. *Eur Heart J*. 2017;38:3523–3531. DOI: 10.1093/eurheartj/ehx363.

20. Kar B, Adkins LE, Civitello AB, Loyalka P, Palanichamy N, Gemmato CJ, Myers TJ, Gregoric ID, Delgado RM III. Clinical experience with the TandemHeart percutaneous ventricular assist device. *Tex Heart Inst J*. 2006;33:111–115.

21. Schwartz BG, Ludeman DJ, Mayeda GS, Kloner RA, Economides C, Burstein S. Treating refractory cardiogenic shock with the TandemHeart and Impella devices: a single center experience. *Cardiol Res*. 2012;3:54–66. DOI: 10.4021/cr121w.

22. 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. DOI: 10.1007/s40119-019-00152-8.

23. Ton V-K, Xie R, Hernandez-Montfort JA, Meyns B, Nakatani T, Yanase M, Shaw S, Pettit S, Netuka I, Kirklin J, et al. Short- and long-term adverse events in patients on temporary circulatory support before durable ventricular assist device: an IMACS registry analysis. *J Heart Lung Transplant*. 2020;39:342–352. DOI: 10.1016/j.healun.2019.12.011.

24. Acharya D, Loyaga-rendon R, Morgan CJ, Sands KA, Pamboukian SV, Rajapreya I, Holman WL, Kirklin JK, Tallaj JA. INTERMACS analysis of stroke during support with continuous-flow left ventricular assist devices: risk factors and outcomes. *JACC Heart Fail*. 2017;5:703–711. DOI: 10.1016/j.jchf.2017.06.014.

25. Patel CB, Blue L, Cagliostro B, Bailey SH, Entwistle JW, John R, Thohan V, Cleveland JC Jr, Goldstein DJ, Uriel N, et al. Left ventricular assist systems and infection-related outcomes: a comprehensive analysis of the MOMENTUM 3 trial. *J Heart Lung Transplant*. 2020;39:774–781. DOI: 10.1016/j.healun.2020.03.002.

26. Devore AD, Hammill BG, Patel CB, Patel MR, Rogers JG, Milano CA, Hernandez AF. Intra-aortic balloon pump use before left ventricular assist device implantation: insights from the INTERMACS Registry. *ASAIO J*. 2018;64:218–224. DOI: 10.1097/MAT.0000000000000629.

27. Hernandez-Montfort JA, Xie R, Ton VK, Meyns B, Nakatani T, Yanase M, Pettit S, Shaw S, Netuka I, Kirklin J, et al. Longitudinal impact of temporary mechanical circulatory support on durable ventricular assist device outcomes: an IMACS registry propensity matched analysis. *J Heart Lung Transplant*. 2020;39:145–156. DOI: 10.1016/j.healun.2019.11.009.

28. Kurihara C, Kawabori M, Sugiura T, Critsinelis AC, Wang S, Cohn WE, Civitello AB, Frazier OH, Morgan JA. Bridging to a long-term ventricular assist device with short-term mechanical circulatory support. *Artif Organs*. 2018;42:589–596. DOI: 10.1111/aor.13112.

29. Morici N, Oliva F, Ajello S, Stucchi M, Sacco A, Cipriani MG, De Bonis M, Garascia A, Gagliardone MP, Melisurgo G, et al. Management of cardiogenic shock in acute decompensated chronic heart failure: the ALTSHOCK phase II clinical trial. *Am Heart J*. 2018;204:196–201. DOI: 10.1016/j.ahj.2018.07.009.

30. Fried JA, Masoumi A, Witer L, Kaku Y, Sumzin N, Roth Z, Clerkin KJ, Griffin JM, Raikhelkar J, Sanchez J, et al. Outcomes of patients bridged with acute mechanical circulatory support devices to HeartMate 3. *J Heart Lung Transplant*. 2020;39:S187–S188. DOI: 10.1016/j.healun.2020.01.776.

31. Clinicaltrials.gov [Internet]. Bethesda, MD: National Library of Medicine (US); 2000 February 29. Identifier NCT04369573, Study on early intra-aortic balloon pump placement in acute decompensated heart failure complicated by cardiogenic shock (Altshock-2); April 30, 2020. Available at: https://clinicaltrials.gov/ct2/show/record/NCT04369573?term=intra-aortic+balloon+pump&draw=2&rank=1. Accessed July 20, 2020.