

Use of Left Ventricular Support Devices During TAVR

Exploring the alternative forms of left ventricular support available to TAVR teams.

BY SAGAR N. DOSHI, MBChB, BSc (Hons), MD, FRCP

Transcatheter aortic valve replacement (TAVR) is now widely and increasingly selected for the treatment of patients with severe symptomatic aortic stenosis at high risk from, or with contraindications to, open heart surgery. The prompt recognition and effective treatment of procedural complications by a multidisciplinary heart team is paramount to successful outcomes in this elderly, high-risk population.

Acute circulatory collapse is an infrequent, but life-threatening complication that may develop during and immediately after TAVR from a number of causes (eg, coronary occlusion, severe aortic regurgitation, cardiac tamponade, valve embolization, and ventricular failure). Immediate circulatory support may be required while the cause of acute compromise is elucidated and remedied. Although mild hemodynamic disturbance may be managed by volume expansion, inotropes, and vasopressors, these interventions are ineffective alone in the face of more profound or total circulatory collapse, and mechanical circulatory support may be needed. Although cardiopulmonary bypass (CPB) has traditionally been used when mechanical support is required in TAVR, a recent survey undertaken in the United Kingdom revealed that only 22 of 33 (67%) TAVR centers had CPB equipment in the catheter laboratory¹ during TAVR, where the vast majority of procedures continue to be performed. CPB may be required if the complication underlying circulatory collapse requires conversion to open heart surgery, but other less invasive forms of circulatory support may allow stabilization and treatment of a patient where open heart surgery is not required or is less desirable and may offer certain advantages.

Alternative options for mechanical circulatory support currently available include intra-aortic balloon counter-

pulsation (IABP), extracorporeal membrane oxygenation (ECMO), Impella, TandemHeart (CardiacAssist), and automated chest compression devices (AutoPulse; Zoll Medical Corporation). However, there are limited data to guide physicians on the optimal device for circulatory collapse during TAVR. In this article, these alternative forms of left ventricular support available to TAVR teams are discussed, highlighting advantages and disadvantages.

INTRA-AORTIC BALLOON COUNTERPULSATION

In balloon counterpulsation, a helium-filled balloon catheter is positioned in the descending aorta with balloon inflation timed to occur in diastole and rapid deflation in systole (Figure 1). This has the effect of increasing diastolic pressure and, in consequence, coronary perfusion and reduces left ventricular afterload. A modest increase in cardiac output is observed, but markedly less than with other forms of invasive mechanical circulatory support (Table 1). Although IABP is widely available and may be quickly implanted, it has many potential limitations in TAVR. IABP may worsen aortic regurgitation, which may be the cause of circulatory collapse and is indeed contraindicated in this setting. It is ineffective in cardiac arrest with circulatory standstill and requires a stable heart rhythm for optimal function. Thus, IABP may only be suitable in some TAVR emergencies.

TANDEMHEART

TandemHeart aspirates oxygenated blood from the left atrium via a cannula implanted via the femoral vein and injects pressurized blood continuously through an arterial cannula placed in the descending aorta (Figure 1). A 21-F long cannula is placed in the left atrium and a 15-

TABLE 1. COMPARISON OF PERCUTANEOUS LEFT VENTRICULAR SUPPORT DEVICES

	IABP	Impella 2.5 L	Impella 3.8 L	Impella 5 L	TandemHeart	ECMO
Augmentation of CO (L/min)	0.3–0.5	2.5	3.8	5	3.5–4	> 4.5
Vascular access	7–9-F femoral artery	13-F femoral artery	14-F femoral artery	22-F subclavian artery or femoral artery	21-F inflow left atrium (TS); 15/17-F outflow via femoral artery	18–21-F inflow right atrium; 15–22-F outflow via femoral artery
Cannula implantation technique	Seldinger	Seldinger	Seldinger	Surgical cutdown	Surgical, trans-septal puncture	Surgical or Seldinger
Ease of implantation	++++	+++	+++	++	+	++
Pump mechanism	Pneumatic	Axial	Axial	Axial	Centrifugal	Centrifugal
Rhythm dependent	Yes	No	No	No	No	No
Oxygenator	No	No	No	No	No	Yes

Adapted from Basra SS, Loyalka P, Kar B. Current status of percutaneous ventricular assist devices for cardiogenic shock. *Curr Op Cardiol*. 2011;26:548-554.

to 17-F cannula in the femoral artery. Placement of the left atrial cannula requires an operator skilled in trans-septal puncture and may be difficult to perform in total circulatory collapse, particularly during chest compressions. The device unloads the left heart, reducing cardiac workload and cardiac oxygen demand and increases cardiac output by up to 4.5 L/min (Table 1). TandemHeart was used successfully to support an 82-year-old patient with circulatory arrest due to left main stem occlusion after TAVR.² The device allowed emergency complex percutaneous coronary intervention to be undertaken with a good outcome and survival out to more than 18 months. Although bleeding complications have been an issue with longer-term support, with TandemHeart, the main limitations for its use in TAVR are the need for expertise in transseptal puncture, the increased time required to establish circulatory support, and the limited experience and familiarity of heart teams with its operation and insertion.^{3,4}

IMPELLA

The Impella catheter is a miniaturized axial pump on a 9-F catheter and is available in three sizes. The smallest device produces an additional 2.5-L/min cardiac output, the intermediate device (CP) gives an additional 3.8-L/min augmentation, and the largest device increases cardiac output by up to 5 L/min (Table 1). The 2.5-L and CP device require 13-F and 14-F femoral sheaths, respectively, and may be

inserted percutaneously, while the 5-L device requires a 22-F sheath and typically requires surgical cutdown to the subclavian or femoral artery. The inlet of the device is positioned in the left ventricle (Figure 1) and continuously aspirates blood from the left ventricle, ejecting the expelled blood into the aorta. Impella unloads the left ventricle, reducing left ventricular end diastolic pressure and wall tension and, consequently, decreases left ventricular work and myocardial oxygen demand.⁵

More than 35,000 devices have been implanted worldwide, mainly for support during high-risk percutaneous coronary intervention, making Impella the most widely used percutaneous left ventricular assist device.⁶ In addition, the device is easy to use, can be rapidly implanted, and requires a single arterial access. The relatively small access required means that both the 2.5-L and CP devices may be inserted through the access sheaths used for TAVR, and thus circulatory support can be quickly established. Successful use of the 2.5-L Impella has been described during circulatory arrest after TAVR with a Sapien valve (Edwards Lifesciences Corporation) in two cases; in one case due to tamponade and the other due to acute aortic regurgitation. In both cases, the 2.5-L Impella allowed successful stabilization and treatment of the patients, with both patients surviving the TAVR procedure and with removal of the device before leaving the operating theater.⁷ Importantly, no abnormality of valve function

was seen of the newly implanted TAVR prosthesis on echocardiography, either acutely or at follow-up.

Although Impella is relatively contraindicated in untreated severe aortic stenosis because of theoretical concerns that effective orifice area may be reduced, multiple reports have demonstrated that Impella implantation is feasible in patients with severe aortic stenosis and may improve the tolerability and safety of balloon valvuloplasty and high-risk percutaneous coronary intervention.⁸⁻¹² Balloon valvuloplasty can be performed with Impella in situ with no apparent loss of function of the device.

EXTRACORPOREAL MEMBRANE OXYGENATION

The ECMO system consists of a centrifugal pump, a heat exchanger, and membrane oxygenator (Figure 1). In femoral ECMO, venous blood is aspirated through an 18- to 21-F cannula placed in the right atrium through the femoral vein (Table 1). Blood is oxygenated and returned under pressure to the descending aorta via a 15- to 22-F cannula introduced via the femoral artery. Implantation times are generally shorter than that required for

TandemHeart, but require replacement of the arterial cannula used for TAVR and insertion of a large gauge venous cannula. Shortened insertion times also require the equipment to be primed and may require additional staff (perfusionists). In a single-center study, ECMO was used for circulatory and/or respiratory support in 10 of 230 patients undergoing TAVR (4.3%). All but two patients received femoral ECMO. The median duration of ECMO support was 87 minutes, and 7 of the 10 patients survived to discharge.¹³ Of the mechanical left ventricular support devices available, only ECMO has the capability of oxygenation, which may be an advantage if profound respiratory compromise is also present.

AUTOPULSE

AutoPulse is a novel, automated external cardiac compression band. The device consists of a constricting band and backboard (Figure 2), which is powered by a rechargeable battery pack that allows continuous automated compressions to be delivered for up to 45 minutes. The apparatus is easy to use, portable, can be employed during concomitant percutaneous coronary intervention, and requires minimal staff training.¹⁴

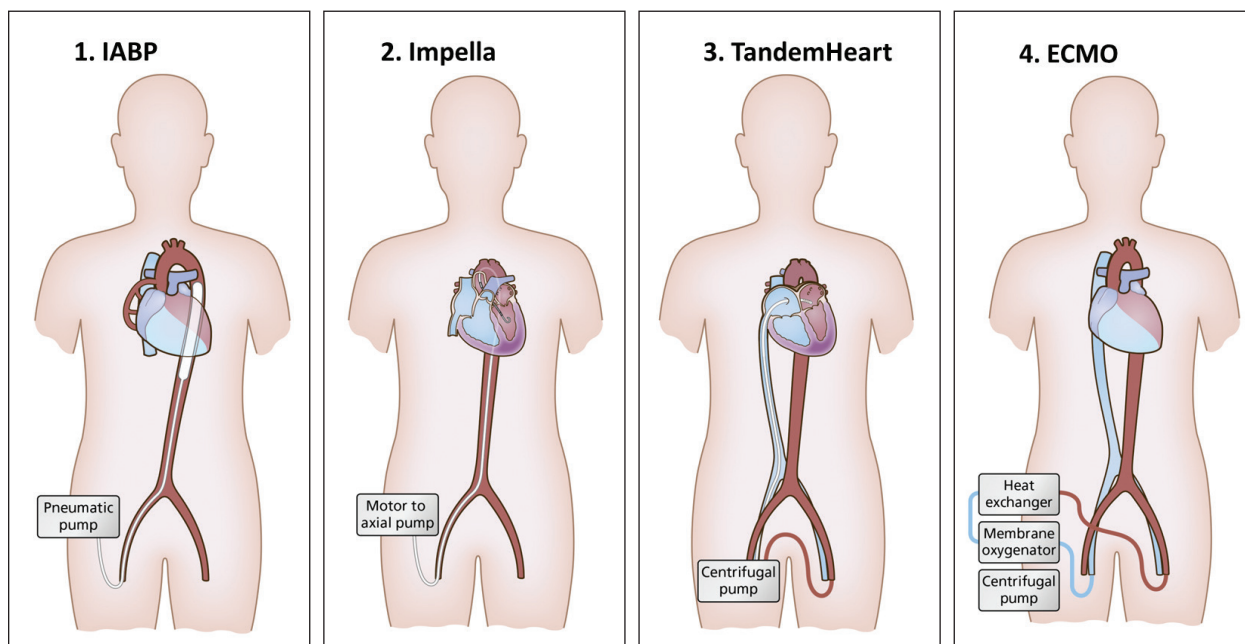


Figure 1. Schematic diagram illustrating the placement of percutaneous left ventricular (LV) support devices. Panel 1–IABP: inflation of a helium-filled balloon in the descending aorta results in increased coronary perfusion and LV afterload reduction. Panel 2–Impella: the catheter is placed in the LV and an axial flow, rotary blood pump continuously withdraws blood from the LV cavity, ejecting blood into the ascending aorta. Panel 3–TandemHeart: a centrifugal pump withdraws blood from the left atrium and ejects blood back into the arterial circulation via the femoral artery. Panel 4–ECMO: venous blood is removed via a catheter placed in the inferior vena cava. A centrifugal pump then passes the blood over a membrane oxygenator before returning (oxygenated) blood to the descending aorta. Reprinted with permission from Spiro J, Doshi SN. Use of left ventricular support devices during acute coronary syndrome and percutaneous coronary intervention. *Curr Cardiol Rep.* 2014;16:544.

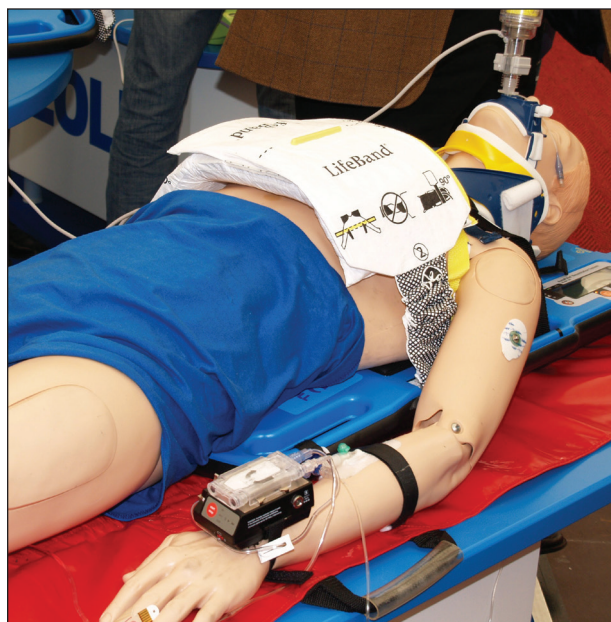


Figure 2. Manikin with AutoPulse attached. The device consists of a band connected to a board placed under the subject. Automated chest compressions are delivered with the device. The device can be activated continuously or with pauses for ventilation.

The device measures chest size and resistance before it delivers a unique combination of thoracic and cardiac chest compressions. The compression depth and force varies per patient, and chest displacement equals a 20% reduction in the anterior-posterior chest depth. Due to its position on the chest, AutoPulse placement may make access difficult for pericardiocentesis in cardiac tamponade. AutoPulse may also be suboptimal for hemodynamic instability complicating surgical TAVR with access through the chest wall (transapical, trans-aortic, and subclavian) due to concerns over maintaining sterility of the access site. The device can effectively maintain circulation during complete circulatory arrest (Figure 3). Compared with manual external massage, AutoPulse affords greater hemodynamic support with larger improvements in diastolic, systolic, and mean arterial pressure during cardiac arrest.¹⁵ The controlled deformation of the chest wall with the AutoPulse may also reduce the risk of deformation of the TAVR prosthesis, which has been described with manual chest compressions.¹⁶ Furthermore, manual chest compressions put the operator performing chest compressions at unnecessary risk from harmful ionizing radiation should fluoroscopy be required, for example with coronary occlusion requiring percutaneous coronary intervention. Another advantage of the device is that it may be positioned and acti-

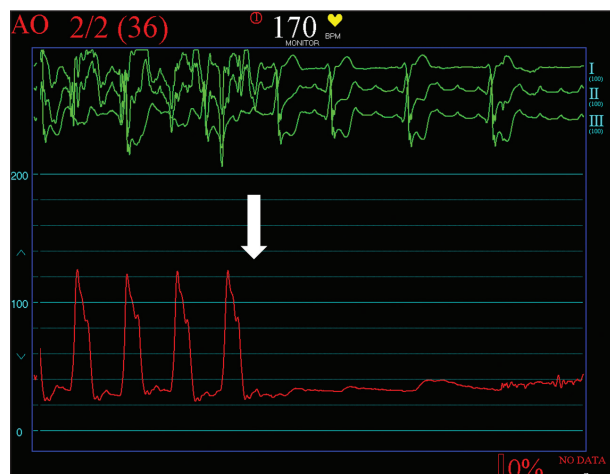


Figure 3. Arterial blood pressure trace with AutoPulse activation during cardiac arrest that followed left main stem occlusion after TAVR. During automated chest compressions, a systolic blood pressure of 120 mm Hg was achieved. The white arrow marks the pause of the AutoPulse with an unassisted blood pressure 40 mm Hg.

vated within 60 seconds. Successful use of the AutoPulse has been described to support a 76-year-old woman in complete circulatory arrest after occlusion of the left main stem after transfemoral TAVR with a Sapien valve for 38 minutes. Successful emergency percutaneous coronary intervention to the left main stem was undertaken during automated chest compressions with the AutoPulse. The patient was well at discharge at 11 days with no focal neurology or cognitive impairment and no evidence of stent deformation on computed tomography at follow-up.¹⁷

CONCLUSION

Effective treatment of acute circulatory collapse remains a challenge for TAVR teams, and a coordinated team approach is necessary for successful outcomes. Successful use of TandemHeart, IABP, AutoPulse, and Impella have been described in the literature during circulatory collapse complicating TAVR. The choice of device will depend on the nature and degree of circulatory compromise and also on the experience, availability, and familiarity of the heart teams with a particular device. Each device has its own particular advantages and disadvantages. IABP, although widely available and easy to operate and implant under emergency settings, is ineffective in total circulatory collapse and may worsen acute aortic regurgitation. ECMO has the advantage of correcting hypoxemia in addition to providing powerful circulatory support, but may require additional staff to support implantation and device operation. Although

TandemHeart provides significant circulatory support, its widespread use is likely to be limited due the requirement of transeptal puncture to place the left atrial cannula, which may be difficult, and possibly hazardous, during cardiac arrest, even in skilled hands. The Impella device is an attractive option to other forms of invasive mechanical support for a variety of reasons. It is widely available, can be rapidly implanted through femoral access sheaths used for TAVR, and provides good circulatory support. AutoPulse may be an attractive option to invasive forms of mechanical support for transfemoral TAVR cases. It may be used in isolation or act as a bridge to other forms of circulatory support. It is easy to use, provides good hemodynamic support, can be deployed within minutes, and is entirely noninvasive.

TAVR teams should consider the options available and have algorithms in place to deal with the catastrophic complication of circulatory collapse. ■

Sagar N. Doshi, MBChB, BSc (Hons), MD, FRCP, is a consultant cardiologist and TAVR program director, Department of Interventional Cardiology, Queen Elizabeth University Hospital in Birmingham, United Kingdom. He has stated that he has no financial interests related to this article. Dr. Doshi may be reached at +44 7979 806314; sagar.doshi@uhb.nhs.uk.

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