Hemodynamic Support Devices for Complex Percutaneous Coronary Intervention

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KEYWORDS

• Ventricular assist devices • Complex coronary intervention • PCI • High risk • Support devices

KEY POINTS

- Increasing complexity of percutaneous coronary intervention (PCI) and high-risk subsets have led to the development and incorporation of hemodynamic support devices to minimize periprocedural risk and improve clinical outcomes, both short term and long term.
- Various hemodynamic support devices for high-risk PCI are currently available, including the intra-aortic balloon pump (IABP), ventricular assist device (VAD), and enhanced extracorporeal membrane oxygenation (ECMO), each with its own inherent risks and benefits as well as technical requirements.
- Data to support high-risk PCIs are available and continue to evolve, and current consensus documents and guidelines support high-risk PCI in unique patient populations.

INTRODUCTION

The field of interventional cardiology has seen rapid advances in technology that have led to the treatment of high-risk patients and complex coronary lesions. These advances include devices that directly aid in the treatment of complex coronary lesions, such as atherectomy devices and advanced guide wires, catheters and further iterations of balloons and stents, and indirect assistance in the form of cardiac assist (hemodynamic support) devices.

Cardiac assist devices can be used in various situations, such as percutaneous valvular procedures, cardiogenic shock, and acute decompensated heart failure; as a bridge to complete circulatory support; and during treatment of elective or urgent high-risk PCI. The focus of this article is on the latter.

Historically, the IABP has been the mainstay cardiac assist device due to its ease of use and wide familiarity and availability. Over the past decade, however, the category of percutaneous assist devices has blossomed to also include Impella 2.5, Impella 5.0, Impella CP, and Impella RP (Abiomed, Danvers, Massachusetts), TandemHeart (Cardiac Assist, Pittsburgh, Pennsylvania) and ECMO. Currently, there is no single unifying definition of high-risk PCI but variables that contribute to elevated risk of adverse outcomes during PCI are well established and can be divided into 3 categories: (1) patient-specific variables, (2) lesion-specific variables, and (3) the clinical setting leading to PCI.

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This article focuses on defining high-risk patients who may benefit from percutaneous assist devices during elective or urgent PCI. For each available percutaneous assist device, the mechanism of action and how it differs from other devices, the clinical data supporting its use, the practical implications for each device, and the current consensus opinion and guidelines for percutaneous assist device utilization are discussed.

DEVICES FOR HIGH-RISK PERCUTANEOUS CORONARY INTERVENTION

During high-risk PCI, the need to maintain hemodynamic stability is of utmost importance, because the device is used to maintain a stable hemodynamic state through a complex procedure with risk of significant ischemia in the setting of baseline cardiac dysfunction. Each device comes with a different mechanism of action and magnitude of hemodynamic support as well as procedural risk, and a proper understanding of each of these is important to guide device selection and anticipate safety and clinical outcomes (Table 1).

While performing high-risk PCI, hemodynamic measurements are essential to guiding management. Particular attention is paid to mean arterial pressure (MAP), cardiac output (CO), and pulmonary capillary wedge pressure. Coronary blood flow (CBF) is dependent on pressure difference across the vascular bed and reciprocally related to resistance to blood flow distally, which correlates with wall tension or left ventricular end-diastolic pressure (LVEDP).[1] Because coronary perfusion occurs during diastole, it is calculated as the pressure difference between the diastolic blood pressure (DBP) and the pressure in the peripheral vascular bed. The following formulae describe these relationships:

Coronary perfusion pressure (CPP) = DBP – LVEDP

CBF = CPP/wall tension (or LVEDP)

LVEDP is also directly proportional to myocardial wall tension. Therefore, any mechanism that can increase DBP, decrease resistance to blood flow, and/or decrease myocardial wall stress/tension increases CBF. An ideal assist device is able to accomplish all of these goals.

Recently, a hemodynamic measurement of cardiac support, namely cardiac power output (CPO), measured in watts, has been discussed for its potential utility in these patients. CPO is MAP multiplied by CO and divided by a constant of 451.[1] This applies the concept that the CO parameter alone is insufficient in predicting sufficient tissue perfusion and blood pressure support. The incorporation of MAP allows better prediction of cardiac decompensation and tissue perfusion and aligns with mortality in patients with cardiogenic shock.[1]

Although supporting systemic and coronary perfusion is an important element of assist devices, these devices also reduce myocardial oxygen demand. Fig. 1 demonstrates the pressure-volume loop of the cardiac cycle, which is helpful in understanding these dynamics. It is bordered inferiorly by the end-diastolic pressure-volume relationship (EDPVR) and superiorly by the end-systolic pressure-volume relationship (ESPVR). Normal hemodynamics dictate that the area within the pressure-volume loop tracks with stroke work (SW), and the area before the flow loop tracks with potential energy (PE) stored in cardiac myocytes. Pressure-volume area (PVA), therefore, is the SW plus the PE and has recently emerged as a potent indicator of myocardial oxygen consumption on a beat-to-beat basis.[1]

PVA = SW + PE

To reduce myocardial oxygen demand, a therapy must move the pressure-volume loop down and to the left (see Fig. 1). Devices, therefore, are measured on whether they move the loop to the left, thereby reducing myocardial oxygen consumption, while at the same time providing optimal CPO and CBF.[2] In this way both the heart and the peripheral organs are prioritized simultaneously during high-risk PCI, minimizing the potential for ischemia by targeting both the supply and demand elements of ischemia and avoiding the downward cycle in contractility and ventricular function that might otherwise occur during unassisted high-risk PCI.

Extracorporeal Membrane Oxygenation

Extracorporal bypass with membrane oxygenator was the first form of mechanical assist device developed. It has the capacity to support a large volume of blood flow. It is, however, greatly hindered by the requirement for a surgical cutdown due to the large size of the arterial and femoral cannulae (20F venous and 17F arterial).[3] First approved in the 1950s for use during cardiac surgery for only several hours, ECMO has evolved over the past decades to become a well utilized option for patients with severe pulmonary and/or cardiac failure.

ECMO is divided into 2 types: venovenous (V-V) or venoarterial (V-A). V-V ECMO is used