High-Risk Percutaneous Coronary Intervention: Challenges and Considerations

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Introduction

Ischemic heart disease remains a leading cause of mortality and morbidity, despite recent advancements in medical and heart failure device therapies [1]. Patients requiring revascularization following myocardial infarction, or for symptoms of angina and heart failure, are often deemed higher risk for periprocedural complications due in part to advanced age and significant medical comorbidities [1, 2]. Many of these patients have anatomic surgical disease but are prohibitive risk for surgery. To address the growing need for minimally invasive revascularization in this aging population, advanced PCI techniques with or without the use of left ventricular support devices have been pioneered, in a growing specialization known as high-risk PCI (HRPCI) [1–3].

Defining High-Risk PCI

HRPCI is defined by specific variables that increase the technical complexity and consequently the potential complications of PCI. These variables can be categorized into three major groups: (a) patient features, (b) anatomic complexity, and (c) clinical hemodynamic factors [1, 2, 4]. Identifying and optimizing these variables is critical to improving HRPCI success and minimizing complications.

Patient Features

Specific patient-associated variables contribute to both procedural and clinical success. Advanced age, frailty, reduced left ventricular (LV) systolic function (EF < 35%), diabetes mellitus, chronic kidney disease, congestive heart failure, female sex, prior MI, peripheral artery disease, and multivessel CAD are all associated with adverse outcomes after PCI [1, 4, 5].

Older patients, compared with younger patients, have a higher prevalence of complications associated with PCI, including access site complications, bleeding, post-procedural MI, and death. Patient frailty, regardless of the modality of revascularization, increases the risks of morbidity and mortality [1, 4, 5].

Another important variable contributing to procedural outcomes is reduced LV function. Several studies have reported increased major adverse cardiac events, in- and out-of-hospital mortality, non-fatal MI, stent thrombosis, and need for target vessel revascularization after PCI in patients with reduced LVEF [1, 4, 5].

The incidence and prevalence of diabetes have substantially increased in the past 10 years, as has the number of patients requiring revascularization. Patients with diabetes are more likely to have diffuse multivessel CAD and impaired LV function than those without diabetes [1, 4–6].

Renal insufficiency affects both short and long-term outcomes in PCI. Numerous studies have indicated a direct correlation between creatinine clearance and PCI outcomes. Lower creatinine clearance is
associated with elevated likelihood of cardiovascular mortality and risk of further worsening of renal function with contrast-induced nephropathy [1, 4–6]. Patients with severe renal insufficiency are also more likely to have other contributing comorbidities, such as advanced age, diabetes, and hypertensive heart disease; additionally, these patients tend to have anatomically more complex and calcified multi-vessel CAD and, more frequently, require mechanical atherectomy [1, 6].

**Anatomic Complexity**

Angiographic success, defined as post-procedural residual stenosis <20% after PCI, is an important factor in achieving good clinical outcomes. The primary determinant of angiographic success is the target lesion characteristics. High-risk anatomic subsets include unprotected left main coronary artery stenosis, true bifurcation lesions (Medina 1/1/1, 1/0/1, 0/1/1), last remaining patent vessel, heavily calcified lesions, chronic total occlusions, saphenous vein graft lesions, and ostial stenoses [1, 4, 6]. The SYNTAX model was developed to stratify anatomic complexity by including lesion characteristics. Patients are grouped by score, with scores of 22 or lower indicating low anatomical complexity, scores of 23–32 indicating intermediate complexity, and scores above 33 indicating high complexity [1, 2, 5]. The SYNTAX II score, a refinement of the original SYNTAX score, incorporates both anatomical and clinical factors. This scoring system assists operators in decision-making regarding the optimal treatment strategy for patients with complex CAD [1].

**Hemodynamic Status**

Pre-intervention hemodynamics and the acuity of patient presentation are strong predictors of adverse outcomes of HRPCI. Patients with acute coronary syndrome, reduced left ventricular systolic function, and/or acutely decompensated heart failure accompanied by elevated left-sided filling pressures face an overall elevated risk of major adverse events [1, 2, 4–6]. Individuals within this cohort often lack the physiological reserve to endure recurrent procedural myocardial ischemia. The extended periods of supine positioning and repetitive left ventricular ischemic challenges during balloon inflations and atherectomy procedures may decrease cardiac output, and compromise myocardial and systemic perfusion [1, 2, 6]. These factors can be mitigated to achieve favorable outcomes through careful patient selection, pre-procedural planning, and the incorporation of adjunctive therapies, such as mechanical circulatory support (MCS) [1, 2, 6].

Numerous observational studies have demonstrated improved procedural cardiovascular hemodynamics with the use of MCS devices [1, 4–11]. The use of such appropriate devices enables decreased myocardial oxygen consumption, increased cardiac output, augmentation of coronary blood flow, and overall increased myocardial and systemic perfusion [1, 7, 10, 11]. These changes in hemodynamics allow for more adequate time to safely perform complex PCI in these high-risk patients who would not otherwise be able to tolerate complete revascularization [5, 7, 10].

For the most precise and accurate evaluation of a patient’s hemodynamic status, right heart catheterization is advisable [1, 2]. This procedure should be performed before a HRPCI to help characterize the patient’s filling pressures and cardiac output. Reassessment of hemodynamic status is also recommended if any adjustments are made to medications or therapies.

**Heart Team**

The use of a collaborative, team-based model is imperative for both the identification and management of patients with high-risk features requiring revascularization. The implementation of a dedicated heart team, comprising at least the patient’s primary cardiologist, consulting interventional cardiologist, and cardiothoracic surgeon, has been shown to improve decision-making, achieve superior outcomes, and ultimately enhance overall patient care [1, 2, 6].

In a collaborative approach, these teams use a comprehensive patient assessment to objectively evaluate the risks and benefits of medical, surgical (CABG), and interventional treatments (HRPCI). The goal of the heart team is to offer unified, clear recommendations to team members, patients, and
their families. This approach not only gathers multiple viewpoints on patient selection and management, but also ensures a balanced perspective in the application of evidence-based guidelines to patient care.

**Device Selection**

Similarly, an integrated risk-benefit decision-making process is essential in considering the appropriateness of MCS in HRPCI. This process involves a careful evaluation to determine which patients are most likely to derive benefits from MCS, and to select the safest and most effective device based on the patient’s specific clinical presentation.

The use of MCS in HRPCI is aimed at addressing the heightened risk of MI and hemodynamic compromise associated with the procedure. The primary goals of MCS are to decrease myocardial oxygen consumption, and maintain adequate cardiac output and myocardial and systemic perfusion during PCI, particularly in situations with high risk of circulatory collapse [1, 6, 7, 11]. Using appropriate MCS devices advantageously allows for adequate time for the operator to safely perform HRPCI, and can achieve optimal results in patients who might otherwise struggle with complete revascularization. Although the timing of MCS device insertion remains controversial, observational studies have shown an increased benefit-to-risk ratio when an upfront strategy is chosen before HRPCI [1, 2, 5]. Whereas various patient- and lesion–specific factors are known predictors of adverse outcomes after PCI, the development of a risk score to assess the need for MCS during HRPCI requires further research. Despite the lack of a specific risk calculator, many operators consider the use of MCS devices in patients with severely reduced left ventricular systolic function and anatomically complex CAD.

The selection of the appropriate MCS device is determined by the specific level of support necessary for the individual patient. Each device has advantages and specific considerations, and the choice is often tailored to the patient’s anatomy and clinical condition. Additional considerations in selecting an MCS modality are adequacy of vascular access, device contraindications, and operator experience.

At present, four MCS devices are frequently used: the intra-aortic balloon pump (IABP), Impella (Abiomed Inc., Danvers, Massachusetts), TandemHeart (Cardiac Assist, Inc., Pittsburgh, Pennsylvania), and veno-arterial extracorporeal membrane oxygenation (VA-ECMO) [1, 2, 4–6].

Selection among the available MCS devices requires recognizing that these devices offer varying levels of hemodynamic support, ranging from 0.5 L/min with IABP to 5 to 6 L/min with VA-ECMO [1, 7–9]. Considerations regarding vascular access limitations play a major role in device selection. For instance, alternative access points, such as subclavian cutdown, transcaval access, or percutaneous axillary access, have been shown to be feasible and safe for devices such as IABP and Impella.

Furthermore, device-specific contraindications must be considered. All MCS platforms except IABP require patients to tolerate systemic anticoagulation. Impella is contraindicated in patients with a mechanical aortic valve and the presence of a left ventricular thrombus. TandemHeart requires an adequately functioning right ventricle and stable rhythm. VA-ECMO may lead to ventricular distention and pulmonary edema if the ventricle cannot adequately be vented [5, 7, 11].

**IABP**

The IABP has seen widespread use because of its favorable cost, high availability, and ease of use. Observational studies have suggested that upfront IABP insertion may result in lower rates of major adverse cardiac events than observed with ad hoc procedures in HRPCI [5, 7, 8]. The Elective Intra-aortic Balloon Counterpulsation During High-risk Percutaneous Coronary Intervention (BCIS-1) trial prospectively studied MCS with IABP in elective high-risk PCI [8]. A total of 301 patients with severely reduced LV function (EF < 30%) without shock were randomized to receive IABP insertion before HRPCI or standard PCI. Although the BCIS-1 trial was not powered to examine all-cause mortality, long-term follow-up at 5 years indicated a statistically significant decrease in all-cause
mortality in the routine IABP group [8]. Upfront IABP may be considered a reasonable option in patients at particularly high risk of hemodynamic decompensation, particularly when larger device insertion is prohibited by poor vascular access.

**Impella**

The Impella is a catheter-based continuous flow ventricular assist device that pumps blood from the left ventricle to the ascending aorta. The safety and feasibility of this device were investigated in the PROTECT I trial, a prospective trial investigating the use of the Impella 2.5 system in patients undergoing HRPCI. A total of 20 patients undergoing HRPCI, defined as unprotected left main coronary artery or last remaining conduit with an LVEF less than or equal to 35%, underwent Impella 2.5 insertion before PCI. This registry study demonstrated that the Impella 2.5 was safe and provided hemodynamic support during HRPCI. Because of the elevated rate of vascular complications with large bore devices, a research priority in the HRPCI field is assessing the comparative effectiveness of one MCS device over another [1, 7, 10]. The PROTECT II randomized trial comparing Impella 2.5 and IABP for HRPCI has indicated no difference in 30-day incidence of MACCE, with a trend toward improved outcomes in the Impella arm at 90 days [1, 4, 7, 10]. The combination of these two trials led to FDA approval for Impella use in HRPCI, which was followed by rapid uptake of this technology in HRPCI. However, because of a failure to meet the primary endpoint in PROTECT II, the largest trial of Impella versus control in HRPCI powered for long-term outcomes is ongoing (PROTECT IV).

**TandemHeart**

The TandemHeart is an extracorporeal centrifugal pump designed to establish a left atrium to femoral artery bypass capable of delivering support up to 4–5 L/min. Operators must be experienced and proficient in trans-septal punctures, which may not be a universally available option at all medical centers. Although this requirement restricts the widespread use of this device, the TandemHeart remains a viable choice in specific scenarios. Its design is particularly appealing for patients with LV thrombus, severe aortic valve disorder, and/or a mechanical aortic valve [1, 2, 5, 6].

Currently, no randomized data support the use of the TandemHeart device in high-risk PCI. However, observational registry studies have demonstrated its effectiveness in patients with the aforementioned clinical conditions requiring enhanced hemodynamic support [1, 6]. Studies have also indicated the device’s acceptable safety and feasibility in high-risk PCI. Despite providing superior hemodynamic support, the use of TandemHeart is associated with elevated vascular site complications, including bleeding and limb ischemia [1, 6].

**VA-ECMO**

VA-ECMO offers comprehensive circulatory support and is a viable choice for patients with severe biventricular failure. This modality can achieve circulatory flow rates as high as 7 L/min, but it poses a significantly elevated risk of bleeding and vascular complications [1, 6].

Bleeding, a common occurrence with ECMO, is not confined to cannulation sites, and can also occur in the brain and gastrointestinal tract. The use of a distal perfusion cannula may mitigate the risks of lower extremity ischemia. Other concerns associated with ECMO include left ventricular distention due to retrograde blood flow and the loss of cardiac pulsatility, thereby leading to conditions such as pulmonary edema and/or intracardiac thrombus [1, 2, 6].

Limited data are available regarding the use of VA-ECMO in HRPCI. However, experiences at individual centers have indicated that performing PCI in a carefully selected group of inoperable patients is feasible and provides excellent hemodynamic support. VA-ECMO can assume control of the entire cardiac output, thereby providing biventricular support along with comprehensive gas exchange [1, 2]. Importantly, in the absence of an LV venting strategy, the use of VA-ECMO has been associated with elevated LV systolic and diastolic pressures, decreased stroke volume, and a subsequent flow-dependent increase in afterload and left ventricular end-diastolic pressure [1, 2]. Consequently, LV venting, assisted by devices such as Impella or IABP, may ultimately be necessary [2].
Conclusion

As global life expectancy increases, cardiologists increasingly face challenges of caring for an older population requiring complex coronary revascularization. A substantial portion of these patients are deemed unsuitable for surgery because of their comorbidities, coronary lesion characteristics, and hemodynamic status. In response to the therapeutic needs of this patient cohort, innovative devices and techniques have been developed to provide viable options for treatment.

In assessing these patients, the heart team approach is critical, to identify anatomic, hemodynamic, and procedural characteristics that favor adjunctive MCS support. The available data support using adjunct MCS devices in patients with severely reduced LV function (EF < 35%) or in acute decompenated heart failure in the presence of complex coronary artery disease [1, 2, 6].

Given the considerable morbidity and mortality risks in patients undergoing high-risk and complex PCI, thorough clinical and invasive hemodynamic assessments are essential before MCS devices are selected, and revascularization is performed. The choice of MCS device depends on multiple factors, including patient anatomy, device availability, local operator expertise, the required amount of hemodynamic support, and technical characteristics such as ease of deployment and removal. Currently, the most widely used device is an IABP, which is followed by Impella, TandemHeart, and VA-ECMO. Generally, more severe clinical and anatomic circumstances are associated with greater potential benefits of MCS use. The timing of insertion remains controversial, but sufficient observational data support a recommendation of initiating MCS support before the commencement of PCI; in most cases, MCS devices can be removed immediately after the intervention. Continuous hemodynamic monitoring with a pulmonary arterial catheter is encouraged at the earliest opportunity to tailor therapy, and to assist in determining the amount and duration of MCS support needed [1, 6, 7, 10].

Future Directions

Additional research is needed to understand the patient and device characteristics associated with technical and clinical success after HRPCI. Moreover, MCS devices, with their various advantages and disadvantages, must be directly compared to establish which devices optimize patient outcomes. These devices should not be considered the standard of care for every complex procedure; instead, the use of MCS devices should be individualized to selective patients after a comprehensive review of their risks and benefits through a heart-team approach.

Conflicts of Interest

The authors have no conflict of interest to declare.

REFERENCES


